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Volume I. State of the Art

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16. ABSTRACT

The purpose of this project was to study processing equipment and systems to convert municipal solid waste (MSW) into a fuel or a fuel feedstock. The first phase was to review the present state of the art and identify the research needs required to advance the technology of waste-to-energy systems. Test plans were then formulated and field tests conducted to meet some of the research needs. The study is intended to provide information useful in the design, selection and operation of fuel and feedstock preparation equipment for existing and future waste-to-energy systems.

Volume I presents the results of the first phase of the project and covers two principal subjects: (1) the present state of the art, and (2) the additional research needs concerning processing equipment for waste-to-energy systems. A major part of the first phase was conducted in the period March through December 1975.

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Volume I. State of the Art

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DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

During the course of this research, some manufacturers who were contacted regarding their processing equipment requested that their names not be used or that their names not be directly associated with particular pieces of equipment. In order to honor these requests and maintain consistency, information from manufacturers' literature and generalized replicas of drawings of equipment are not sourced.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report presents the results of a study of equipment and systems for processing municipal solid wastes into energy related products. The study was divided into three phases. The first phase, reported herin, was devoted to a study of the state of the art and formulation of research needs. The second phase, was devoted to field tests of magnetic separators, air classifier and air emissions. The third phase was involved with field tests of shredders.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The purpose of this project was to study processing equipment and systems to convert municipal solid waste (MSW) into a fuel or a fuel feedstock. The first phase was to review the present state of the art and identify the research needs required to advance the technology of waste-to-energy systems. Test plans were then formulated and field tests conducted to meet some of the research needs. The study is intended to provide information useful in the design, selection and operation of fuel and feedstock preparation equipment for existing and future waste-to-energy systems.

Vol I presents the results of the first phase of the project and covers two principal subjects: (1) the present state of the art, and (2) the additional research needs concerning processing equipment for waste-to-energy sustems. A major part of the first phase was conducted in the period March through December 1976.

The methodology used to establish the state of the art included a literature search, a survey of present and planned waste-to-energy systems, the compiliation of available information on equipment used in these systems, visits to plan sites, and discussions with system designers, system operators, equipment manufacturers, and other knowledgeable people.

Over 200 pertinent reports and other literature were assembled and reviewed. Ninety MSW processing programs throughout the country were surveyed, including 54 waste-to-energy plants using processing equipment. Fourteen of these waste-to-energy plants were scheduled to be operational by 1978.

A comprehensive investigation of the processing equipment being used or planned for a waste-to-energy systems expected to be operational by 1978, as well as other MSW processing plants, was conducted. Detailed data were gathered from the literature and from manufacturers' specifications. To obtain firsthand information, project personnel visited seven waste-to-energy plan sites, held discussions with responsible representatives of ten organizations which have designed waste-to-energy systems, and held discussions with representatives of 16 organizations which manufacture and/or distribute equipment.

Fourteen waste-to-energy systems expected to be operational in 1978 are described, including the type of system, designer's name, operational dates, capacity, and processing operations employed to produce the energy product. Also given are performance problems and the potential of the plan as a site for conducting tests.

Processing equipment used to convert MSW into energy products may be classified into two broad categories: (1) unit equipment, and (2) supplementary equipment. Unit equipment is defined as equipment which changes the character of waste stream and includes shredders, magnetic separators, air classifiers, screens, dryers and densifiers. Supplementary equipment is defined as equipment which aids in the processing of the MSW but does not change the character of the waste stream; included are receiving facilities, conveyors, storage and retrieval bins, electrical controls, dust controls, and fire and explosion controls. The state of the art of unit and supplementary equipment for present and planned waste-to-energy systems is described, including the various types within each category. The function, physical description, and experience with MSW are given for each type of equipment.

The investigation into the present state of the art of processing systems and equipment for waste-to-energy applications revealed the need for considerable additional research. Important information need by equipment manufactuers, system designers, and system users is lacking. Equipment manufacturers need to know more about the conditions under which their equipment will be operated, and how well their equipment actually performs under plan conditions. System designers require more performance data about alternative pieces of equipment and systems so that they can make choices based on firm comparative data. Systems users need more information concerning the optimal conditions for operating and maintaining individual pieces of equipment and systems, based on cost-effectiveness data, which is presently lacking.

Forty specific research needs are identified. A description of each of these research needs is presented, including the background, a statement of the objective(s), and research approach.

This report was submitted in partial fulfilment of Contract No. 68-03-2387 by Midwest Research Institute under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period March through December 1976 with some updating during the summer of 1978.

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SECTION 1

INTRODUCTION

The combined need for new energy sources and better waste disposal techniques in the U. S. has stimulated considerable interest and activity in the recovery of energy and other resource from municipal solid waste (MSW). A variety of energy recovery systems have been designed which produce waste-derived fuels in solid, liquid or gaseous forms. Processed MSW may be used directly as a solid fuel in power plants boilers and other industrial heaters, or as a feedstock for pyrolysis and other systems which convert the processed MSW into liquid or gaseous fuels. The raw waste is processed through various combinations of equipment which usually include one or more of the following unit operations: shredding, magnetic separation, air classification, screening, drying, and densification. In addition to these unit operations, these systems usually also include, receiving facilities, conveyors, dust collectors, cyclone separators, electrical controls, storage and retrieval bins, and other ancillary equipment.

Much of the equipment presently being used for waste-to-energy systems was not originally designed for use on municipal solid waste, which is a difficult material to handle and process. Some characteristics that make MSW difficult to handle and process are: (1) it is a mixture of many different materials and shapes; (2) the moisture content can vary considerably; (3) it does not flow well; (4) it contains abrasives; (5) it is putrescible; and (6) it tends to compact in storage. Thus far, operating experience, tests and evaluations of waste-to-energy systems have been insufficient to provide a firm basis for optimum design, selection and operation of processing equipment for these systems.

In light of the situation, the U. S. Environmental Protection Agency contracted with Midwest Research Institute to conduct research, tests and evaluations of alternative processing equipment and systems for converting municipal solid waste into a solid fuel for feedstock for liquid/gaseous fuel conversion systems. The project was intended to stimulate and advance the technology of waste-to-energy systems by providing information useful to equipment manufacturers, system designers and system operators

Phase I of the study, reported herein, was concerned with (1) a study of the present state of the art of equipment used to process MSW into energy-related products,* and (2) the identification of areas which require additional research to improve the state of the art. Phase I was conducted during the period March through Devember 1976, with some updating in the summer of 1978.

Phases II and III were devoted to in-plant tests and evaluation of processing equipment, aimed at satisfying some of the research needs.

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* Only equipment which affects the energy-related product streams were included in this study; equipment used to process only the non-energy streams, such as metals and glass recovery, were not included in this study.

SECTION 2

METHODOLOGY AND PRELIMINARY RESULTS

The methodology used to establish the state of the art of waste-to-energy systems and associated processing equipment, and to identify the research needs included: (1) a search of the relevant literature, (2) a survey of present and planned waste-to-energy systems, (3) compilation of available date on associated processing equipment, (4) visits to plant sites, and (5) discussions with system designers and equipment manufacturers.

LITERATURE SEARCH

The purpose of the literature search was to assemble and review available literature relating to the processing of municipal solid waste into fuel or fuel feedstock. The literature consisted of two major components:

1. General literature, including technical reports, journal articles, conference proceedings, books and other reference materials pertaining to waste-to-energy systems, processing operations, and general equipment data; and

2. Manufacturers' literature regarding specific types of processing equipment.

The general literature provided a basis for formulating an initial assessement of the state of the art waste processing technology and for preparing a preliminary list of municipal waste-to-energy systems; it was also utilized as the core of a project library used as a source of references throughout the course of the project. The manufacturers' literature served as a base for the development of equipment data, which is presented in a later section of this report.

The first step in the assembly of relevant literature was a comprehensive review of MRI's existing Solid Waste Library. This library, which houses hundreds of documents relating to solid waste management and resource recovery, was surveyed; and pertinent documents were transferred from the general library to a special project library. Selected Texas A & M literature files were also surveyed for relevant documents, and such documents not already in the MRI library were made available to the project library. Additionally, EPA's bibliography "Solid Waste Management-Available Information Materials," as well as other bibliographies containing solid waste, resource recovery or energy-related documents, were surveyed for materials pertinent to the project; these documents were then ordered. Furthermore, the EPA Project Officer was instrumental in locating and sending a number of pertinent references. Upon receipt, each reference was reviewed to assure its relevance prior to its incorporation into the library. A listing of the references accumulated and reviewed is contained in Appendix A1.

The manufacturers' literature file contains literature from 64 manufacturers of shredders, magnetic separators, air classifiers, screens, driers, storage bins, conveyors and miscellaneous equipment. A listing of companies which manufacture waste processing equipment is given in Appendix A2.

SYSTEMS SURVEY

In addition to the literature review, a survey of all known existing and planned waste-to-energy systems throughout the United States was conducted.* The criteria for systems included in the survey were: (1) that the system produce an energy product, and (2) that the system utilize processing equipment to convert the waste into a fuel or fuel feedstock.

During the course of the literature review, a preliminary list of existing and planned systems was developed. This preliminary list was composed of 90 systems, including municipal facilities, county and regional systems, and pilot plants or demonstration projects.

Contacts were made with representatives of each of these 90 systems to obtain up-to-date information on the system. Initial contacts were made by telephone whenever possible. Followup contacts and communication with those individuals who could not be reached by telephone were conducted by written correspondence. After describing the purpose of the project, MRI staff requirested the following information from each system representative.

1. The type of energy product being or to be produced, if any;
2. The plant capacity;
3. The type of processing operations employed, if any;
4. The designer of the processing system;

---

* The survey of waste-to-energy systems was conducted during the summer of 1976.

5. When and where the system is now, or is planned to be operational; and

6. Whether or not the system will be available for tests.

Additionally, technical reports and economic evaluations were requested when the representatives indicated such materials to be available.

Upon completion of all telephone contacts and receipt of written replies, systems data were then tabluated for each of the systems.

The breakdown of these systems is as follows:

54 systems met the criteria of producing an energy product and utilizing processing equipment
12 systems for which no final decision had been made as to the type of technology to be employed
7 systems not utilizing energy recovery
6 systems did not respond to telephone or wirtten inquiries
4 systems do not use processing operations
2 systems were no longer operational
2 systems were duplicates of other systems in the survey (listed under two different names)
1 system was a test facility, to be superseded by a large-scale facility included in the 54 systems meeting project criteria
1 system was only an experimental plant
1 system for which correspondence was returned, indicating "no such address"

90 systems - total

Table 1 is a listing of the 54 systems meeting the basic project criteria (i.e., producing an energy-related product and utilizing processing equipment). For each system, the type of energy product to be produced, the system designer, and the anticipated operational date are included. Table 2 lists the additional 36 systems surveyed and their status.

From the 54 systems in Table 1, a furhter selection process was undertaken to determine those which were expected to be operational by January 1978. This date was chosen as the time frame necessary for implementation of field tests during the present contract period. Fourteen systems were found to meet this final criterion; these are listed in Table 3.

TABLE 1. WASTE-TO-ENERGY SYSTEMS (WITH PROCESSING)

Name/Location of System	Energy Product	System Designer	Anticipated Operational Date
1. Akron, Ohio	Steam	Glaus, Pyle, Schamer, Burns and Dehaven	December 1979
2. Albany, New York	RDF*	Smith and Mahoney	Spring 1980
3. Ames, Iowa	RDF	HDR	In operation
4. Baltimore Maryland	Steam	Monsanto	Under repair
5. Baltimore County, Maryland	RDF	Teledyne	In operation
6. Bridgeport, Connecticut	RDF	CEA, Occidental	Early 1979
7. Capital District New York	RDF	Horner and Shifrin	Not available
8. Central Contra Costa County, California	Pyrolysis gas	Brown and Caldwell	1979
9. Charleston, West Virginia	Pyrolysis gas	Union Carbide	In operation
10. Chemung County New York	RDF	Americology	Not available
11. Chicago, Illinois	RDF	Parsons-Consoer	Mid-1978
12. Columbus, Ohio	Steam	Jeffrey Manufacturing Company	1980
13. Dade County, Florida	RDF	Black-Clawson	1980
14. Dallas, Texas	RDF	HDR	January 1979
15. Detroit, Michigan	Steam	Being negotiated	Not available
16. Duluth, Minnesota	RDF	Conoer, Townsend And Associates	Janaury 1979
17. East Bridgewater, Massachusetts	RDF	CEA	December 1976
18. El Cajon, California	Pyrolysis liquid fuel	Occidental	Partial operation
19. Erie County, New York	RDF	Horner and Shifrin	March 1978
20. Essex County, New Jersey	RDF	Unknown	Not available
21. Fairmont,	RDF	Joseph Edeskuty	Not available

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* Shredded refuse derived fuel.

TABLE 1. (continued)

Name/Location of System	Energy Product	System Designer	Anticipated Operational Date
22. Hackensack, New Jersey	RDF	Burns and Rowe	Not available
23. Haverhill, Massachusetts	Steam	VOP-Martin	1980
24. Hempstead, New York	Steam	Black Clawson	April 1978
25. Hennepin County, Minnesota	RDF	HDR-feasibility study	Not yet determined
26. Honolulu, Hawaii	Probably gas	Sunn, Low, Tom & Hara	Not available
27. Irvine, California (test facility)	Pyrolysis gas	Barber-Colman	Not available
28. Knoxville, Tennessee	RDF	Black-Clawson	1980
29. Lane County, Oregon	RDF	Allis-Chalmers	Summer 1978
30. Menlo Park, California	Electricity	Combustion Power Company	Under development
31. Middlesex County, New Jersey	Steam or gas	Roy F. Weston	1980 to 1981
32. Milwaukee, Wisconsin	RDF	Americology	Partially operational
33. Monroe County, New Jersey	RDF	Raytheon	Late 1978
34. Montgomery County, Maryland	RDF	Bonnett, Fleming Corddry and Carpenter	July 1979
35. Montgomery County, Ohio	RDF	Unknown	Not available
36. Mt. Vernon, New York	Pyrolysis gas	Union Carbide	Not available
37. New York, New York	RDF	Horner and Shifrin	1980
38. Outagami County, Wisconsin	RDF	Allis-Chalmers	December 1978
39. Palmer Township, Pennsylvania	Fuel Pellets	Elo and Rhodes	1978
40. Pompano Beach, Florida	Methane	Waste Management, Incorporated	May 1978

TABLE 1. (concluded)

Name/Location of System	Energy Product	System Designer	Anticipated Operational Date
41. Portland, Oregon	RDF	Not yet determined	1980
42. Riverside, California	Pyrolysis gas	Pyrolysis Systems, Incorporated	Spring 1977
43. St. Louis, Missouri	RDF	Horner and Shifrin	Inactive
44. San Antonio, Texas	RDF	Unknown	1979
45. Sanitary District No. 1, Lawrence, New York	Pyrolysis	Unknown	Not available
46. Santa Rosa, California	RDF	Lumberman and Sira	Not available
47. Scranton, Pennsylvania	RDF	Metcalf and Eddy	1979
48. Southgate, California	Pyrolysis	Etnerprise Company	In operation (test facility)
49. Springfield, Illinois	RDF	HDR	1979
50. Tampa Bay, Florida	Probably pyrolysis	HDR	Not available
51. Toledo, Ohio	RDF	Samborn, Steketee, Otis and Evans	Late 1978
52. Washington, D. C.	RDF	NCRR	In operation (test facility)
53. Winchester County, New York	RDF	Malcolm Pirnie, Incorporated	Not available
54. Wilmington, Delaware	RDF	Unknown	1980

TABLE 2. ADDITIONAL SYSTEMS SURVEYED

Name	Status
55. Ansonia, Connecticut	No decision
56. Beverly, Massachusetts	No response
57. Chatauqua County, New York	No decision
58. Cuyahoga Valley, Ohio	No preprocessing
59. Evanston, Illinois	No response
60. Ft. Wayne, Indiana	No longer operational
61. Franklin, Ohio	No energy recovery
62. Greensboro, North Carolina	No decision
63. Hamilton, Ontario	No preprocessing
64. Hammond, Indiana	No energy recovery
65. Hartford, Connecticut	No decision
66. Housatonic Valley, Connecticut	No decision
67. Jacksonville, Florida	No response
68. Lancaster, California	No longer operational
69. LaVerne, California	Test facility
70. Lawrence, Massachusetts	No decision
71. Los Gatos, California	Experimental plant
72. Lyndhurst, New Jersey	Same as Hackensack, New Jersey
73. Madison, Wisconsin	No decision
74. Memphis, Tennessee	No response
75. Minneapolis, Minnesota	No energy recovery
76. New Britain, Connecticut	No decision
77. New Jersey, Central	No preprocessing
78. Norwalk, Connecticut	No decision
79. Oakland, California	Resource recovery not part of present plan
80. Oakland County, Michigan	No decision
81. Peoria, Illinois	No response
82. Philadelphia, Pennsylvania	No decision
83. Red Lion, Pennsylvania	No response
84. Richmond, Virginia	No decision
85. Saugus, Massachusetts	No preprocessing
86. Seattle, Washington	No energy recovery
87. Springfield, Missouri	No energy recovery
88. Staten Island, New York	Same as New York, New York
89. Union County, New Jersey	No energy recovery
90. Upland, California	Correspondence returned--no such address

TABLE 3. WASTE-TO-ENERGY SYSTEMS (WITH PROCESSING) SCHEDULED TO BE OPERATIONAL BY 1978

Location	Energy Product	Capacity (Tons Per Day)	Status
1. Ames, Iowa	RDF	360	In operation since 1975
2. Baltimore, Maryland	Pyrolysis (steam)	900	Being redesigned
3. Baltimore County, Maryland	RDF	455	Partly operational since 1976
4. Charleston, West Virginia	Pyrolysis (gas)	182	In operation since 1974
5. Chicago, Illinois	RDF	900	Shakedown
6. East Bridgewater, Massachusetts	Eco-Fuel II	220	In operation since 1976
7. El Cajon, California	Pyrolysis (oil)	180	Shakedown
8. Milwaukee, Wisconsin	RDF	900	Shakedown
9. Palmer Township, Pennsylvania	RDF	135	Shakedown
10. Pompano Beach, Florida	Methane	45-90	Start up 1978
11. St. Louis, Missouri	RDF	270	Inactive
12. Riverside, California	Pyrolysis (gas)	300	Unknown
13. Southgate, California	Pyrolysis (oil)	50	Unknown
14. Washington, D.C.	RDF and Pellets	30	Experimental plant

EQUIPMENT SURVEY

Based on the information compiled in the systems survey, a comprehensive investigation of the processing equipment used at each of the systems expected to be operational by 1978 was undertaken. The equipment survey was concentrated on these systems because of their potential availability for tests within the present project period. Some data were also gathered on the MSW processing systems and equipment which are potentially applicable for waste-to-energy systems.

The initial taks in the equipment survey was to construct a flowchart of the processing equipment used at each of the waste-to-energy systems under consideration. This task was accomplished by using the information collected in the systems survey. Only those pieces of processing equipment which directly affect the energy product (fuel or fuel feedstock) stream were included in the chart, shown in Figure 1. From this chart, a list of processing equipment which are within the scope of this project was compiled. This list, shown in Tables 4 and 5, includes all the major types of equipment and variations within each type.

The next task was to determine what data should be collected for each piece of equipment. To accomplish this task, the literature collected during the literature search, including the manufacturers' literature, was culled for information pertaining to processing equipment specifications and performance. Additionally, information gained in discussions with system designers, plant site visits and from MRI project consultants was used in the design of data sheets.

The equipment data sheets incorporated three major sections: (1) specifications, (2) performance data, and (3) costs. The specifications section include detailed items which are pertinent to the general type of equipment and items which deal with each specific piece of equipment being used or planned for waste-to-energy systems. The performance section relates only to data on the performance of the equipment on MSW. The cost section includes capital, operating, and maintenance costs, also as they relate to performance on MSW.

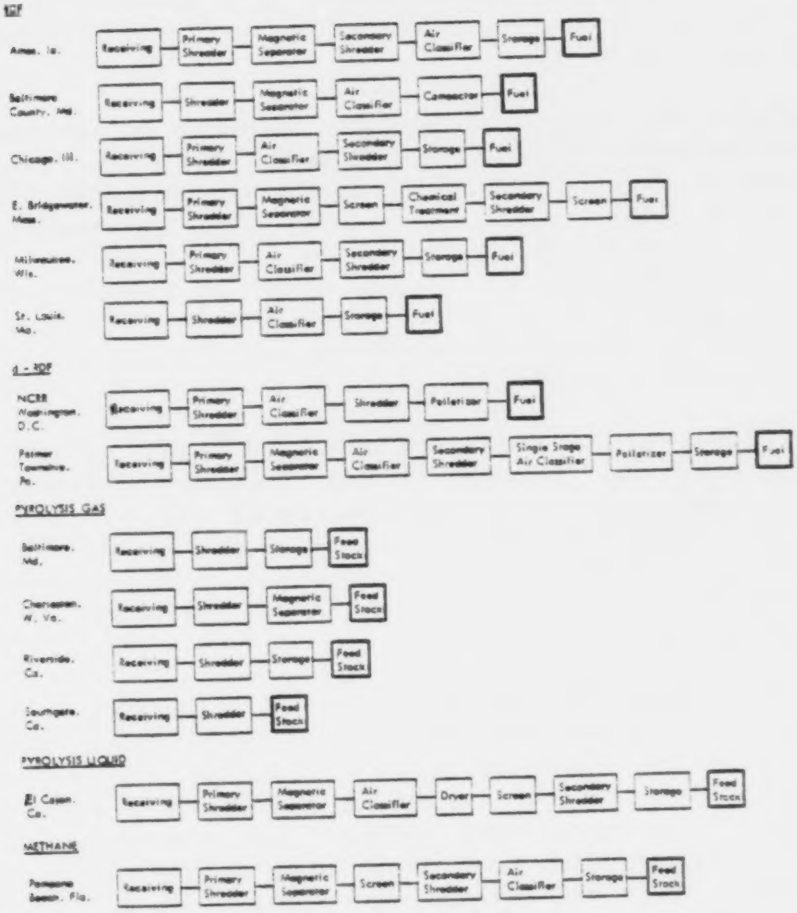

RDF
Ames, Ia.
Receiving
Primary Shredder
Magnetic Separator
Secondary Shredder
Air Classifier
Storage
Fuel
Baltimore County, Md.
Receiving
Shredder
Magnetic Separator
Air Classifier
Compactor
Fuel
Chicago, Ill.
Receiving
Primary Shredder
Air Classifier
Secondary Shredder
Storage
Fuel
E. Bridgewater, Mass.
Receiving
Primary Shredder
Magnetic Separator
Screen
Chemical Treatment
Secondary Shredder
Screen
Fuel
Milwaukee, Wis.
Receiving
Primary Shredder
Air Classifier
Secondary Shredder
Storage
Fuel
St. Louis, Mo.
Receiving
Shredder
Air Classifier
Storage
Fuel
d - RDF
NCRR Washington, D.C.
Receiving
Primary Shredder
Air Classifier
Shredder
Pelletizer
Fuel
Palmer Township, Pa.
Receiving
Primary Shredder
Magnetic Separator
Air Classifier
Secondary Shredder
Single Stage Air Classifier
Pelletizer
Storage
Fuel
PYROLYSIS GAS
Baltimore, Md.
Receiving
Shredder
Storage
Feed Stock
Charleston, W. Va.
Receiving
Shredder
Magnetic Separator
Feed Stock
Riverside, Ca.
Receiving
Shredder
Storage
Feed Stock
Southgate, Ca.
Receiving
Shredder
Feed Stock
PYROLYSIS LIQUID
El Cajon, Ca.
Receiving
Primary Shredder
Magnetic Separator
Air Classifier
Dryer
Screen
Secondary Shredder
Storage
Feed Stock
METHANE
Pompano Beach, Fla.
Receiving
Primary Shredder
Magnetic Separator
Screen
Secondary Shredder
Air Classifier
Storage
Feed Stock

Figure 1. Fuel/feedstock processing systems at 14 plants.

TABLE 4. PROCESSING EQUIPMENT USED IN WASTE-TO-ENERGY SYSTEMS

1. Receiving facilities
    a. Scales
    b. Building
    c. Loaders
    d. Ancillary equipment
2. Conveyors
    a. Flight
    b. Belt
    c. Vibratory
    d. Pneumatic
3. Shredders
    a. Hammermills - vertical, horizontal
    b. Grinders - roller, disc-mill
    c. Flail mill
    d. Wet Pulp
    e. Ball mill
    f. Knife mill
4. Magnetic Separators
    a. Belt type
    b. Drum type
5. Air Classifiers
    a. Straight
    b. Zigzag
    c. Vibrating
    d. Drum
    e. Concentric
6. Screens
    a. Trommel
    b. Vibrating-reciprocating and gyrating
    c. Disc
7. Dryers
    a. Drum-type
    b. Fluid-bed
8. Densifiers
    a. Pelletizers
    b. Briquetters
    c. Cubers
    d. Extruders
    e. Compactors
9. Storage and Retrieval Systems
10. Electrical Control Systems
11. Dust Control Systems
    a. Cyclones
    b. Baghouses
12. Fire and Explosion Control Systems

TABLE 5

TYPES OF PROCESSING EQUIPMENT USED OR PLANNED AT 14 WASTE-TO-ENERGY SYSTEMS

Location	Receiving	Primary Shredder	Magnetic Separator	Chemical Treatment	Air Classifier	Dryer	Screen	Compactor	Secondary Shredder	Pelletizer	Baghouse	Storage Retrieval	Conveyors	Control System
Ames, Iowa	Toledo Scales	American Pulverizer Model 60-90	Dings	--	Rader 130	--	-	--	American Pulverizer Model 60-90	--	--	Atlas	Rader, PSI, Rexnord, Mayfran, Fairfield	NA
Baltimore, Maryland	Fairbanks Scales	Jeffrey Manufacturing Model 994	--	--	--	--	--	--	--	--	Monsanto	Atlas	Jeffrey Manufacturing Rexnord	Monsanto Fisher-Controls
Baltimore County, Maryland	Toledo Scales	Marksman Tracon Toshiba, 1,000 HP	Dings	--	National Resource Recovery	--	--	Heil HT65	--	--	Griffin Environments	--	Iron Hustler	Adex-Computer Teledyne
Charleston, West Virginia	Cat 950 Toledo Scales	Heil Company Model 42D	Eirez SRE/P and SE 565 S/N 26425	--	--	--	--	--	--	--	--	--	Taunton	Union Carbide
Chicago, Illinois	NA	Williams	--	--	Triple/S Vibrolutriator	--	--	Heil HT65	Carborundum	--	Carter-Day	Atlas Chicago and Iron	J.W. Greer, Rexnord, Systems and Engineering Manufacturing	NA
East Bridgewater, Massachusetts	NA	NA	NA	NA	--	--	Rotex 522A Gruendler Triple S	--	--	--	Carter-Day	--	NA	CEA Cleveland Controls
El Cajon, California	NA	American Pulverizer Model 60-90	Stearns	--	Occidental	Guarantee	Rotex 522A	--	Beloit-Jones	--	NA	American Sheet Metal	Mayfran Rexnord	Procon (UOP)
Milwaukee, Wisconsin	NA	Williams	--	--	Americology	--	--	Heil HT65	Heil	--	NA	NA	Rexnord	NA
Palmer Township, Pennsylvania	NA	NA	NA	--	NA	--	NA	--	NA	NA	NA	NA	NA	Rio and Rhodes
Pompano Beach, Florida	NA	Heil Company	NA	--	Triple/S Vibrolutriator	--	--	--	Gruendler	--	NA	NA	NA	NA
Riverside, California	Shallow Pit-Pan Conveyor, Mayfran	--	--	--	--	--	--	--	--	--	NA	Pyrolysis Systems	Carrier Mayfran	NA
St. Louis, Missouri	1 IH 1110 Pickup 3 IH F-1800 Dump 1 IH 3850 Front-end 1 Case W-14 Front-end 3 IH-Heil COF4070A Compactor	Gruendler Model 84-60	--	--	Rader Size 44	--	--	--	--	--	NA	Miller-Hofft	Continental, Rader, Stephens-Adamson	--
Southgate, California	NA	Enterprise 44 X 60	NA	--	--	--	--	--	--	--	--	--	Enterprise Mayfran	Minneapolis Honeywell Barber-Colemen Allen-Bradley
Washington, D.C.	NA	Williams, Model 780	--	--	Triple/S Vibrolutriator	--	Combustive Power	--	Heil	California Pellet Company	--	--	NA	NA

NA = Not available.

The data forms were completed to the extent possible by MRI, using the general manufacturer's literature and the systems literature. They were then sent to the respective manufactueres for verification of information and completion of the forms. When possible, this information was also sought from plant/design personnel.

SITE VISITS

Project personnel vistied seven waste-to-energy plant sites to obtain first-hand information. The plants visited were at Ames, Iowa; El Cajon, California; Washington, D. C.; Baltimore, Maryland; Cockeysville, Maryland; Charleston, West Virginia; Chicago, Illinois; and St. Louis, Missouri. Attempts were made to visit plants in East Bridgewater, Massachusetts, and Milwaukee, Wisconsin, but because these plants were under construction, visits were not permitted.

DISCUSSIONS WITH SYSTEM DESIGNERS

Personal discussions were held with representatives of ten organizations which have designed waste-to-energy systems. The purpose of these discussions was to obtain firsthand information concerning the procedures presently being used to design and select processing systems and equipment for waste-to-energy systems.

The organizations contacted included Horner and Shifrin, Inc., designers of the St. Louis EPA demonstration plant; Monsanto Enviro-Chem Systems, Inc., designers of the Baltimore pyrolysis plant; Henningson, Durham and Richardson, designers of the Ames, Iowa plant; Ralph M. Persons, designers of the Chicago RDF plant; Occidental Research Corporation, developers and designers of the El Cajon pyrolysis plant; Enterprise Company, designers of the pyrolysis plant at Southgate, California; Teledyne National, designers of the Baltimore County RDF plant, Combustion Equipment Associates, developers and designers of the East Bridgewater, Connecticut, Eco-Fuel plant; and Elo and Rhodes, designers of the Palmer Township, Pennsylvania, system, and NCRR, designers of the Washington, D. C., and New Orleans facilities. The individuals contacted at these organizations are listed in Appendix B.

DISCUSSIONS WITH EQUIPMENT MANUFACTURERS

Personal discussions were held with representatives of 16 organizations which manufacture and/or distribute equipment for use in waste-to-energy systems. The purpose of these discussions was to obtain firsthand information on the characteristics of their equipment, the performance of their equipment on MSW, and areas which require additional research.

The organizations included the Gruendler Crusher and Pulverizer Company (shredders and trommels), Williams Patent Crusher and Pulverizer Company (Shredders, conveyors and air classifiers), American Pulverizer Company (shredders), the Heil Company (shredders, dryers, and stationary packers), Dings Company (magnetic separators), W. D. Patterson (distributors of screens, baghouse filters, air classifiers, vibrating feeders, shredders and control devices), Rexnord Company (conveyors), Beloit-Jones (secondary shredders), Fenwal, Inc. (explosion controls), Stearns Magnetics, Inc. (magnetic separators), Carter-Day Company (filters, control systems), Triple S. Dynamics Systems (air classifiers), National Resource Recovery Corporation (air classifiers), Rader Systems (air classifiers, screens). The individuals contacted at these organizations are listed in Appendix B.

SECTION 3

STATE OF THE ART

This section describes the state of the art of waste-to-energy processing in terms of fourteen systems and the equipment comprising those systems. The information presented reflects a diversity of equipment designs, system configurations and overall approaches to the process of refining MSW into energy products. The experience encountered with the equipment and systems is reported, and those areas where substantial data are lacking are introducted as a prelude to the subsequent section on research needs.

WASTE-TO-ENERGY PROCESSING SYSTEMS

As discussed in the previous section, 14 systems were identified which meet the project criteria of producing an energy-related product and utilizing processing equipment, and which were expected to be operational by January 1978. In describing each of these systems, the following information is presented:

General information includes such data as system tape, designer, operational date and capacity.

Processing system describes the various operations employed to produce the energy product and other resources.

Performance problems involves experience relating to the system in general, either during actual operations or preliminary tesing, with emphasis on problems with preprocessing equipment.

Potential as test site examines the factors of accessibility to the facility, scale of the system, and other variables which could affect the viability of testing at each site.

Ames, Iowa

The Ames, Iowa facility, operational since November 1975, produces a refuse-derived fuel product for use in the adjacent Ames Municipal Electric Service Power plant. Ferrous metals and aluminum are also recovered from the MSW. Designed by Henningson, Durham and Richardson, Inc., of Omaha, Nebraska, the facility has a capacity of 45.4 metric tons per hour and is operated about 8 hours per day.

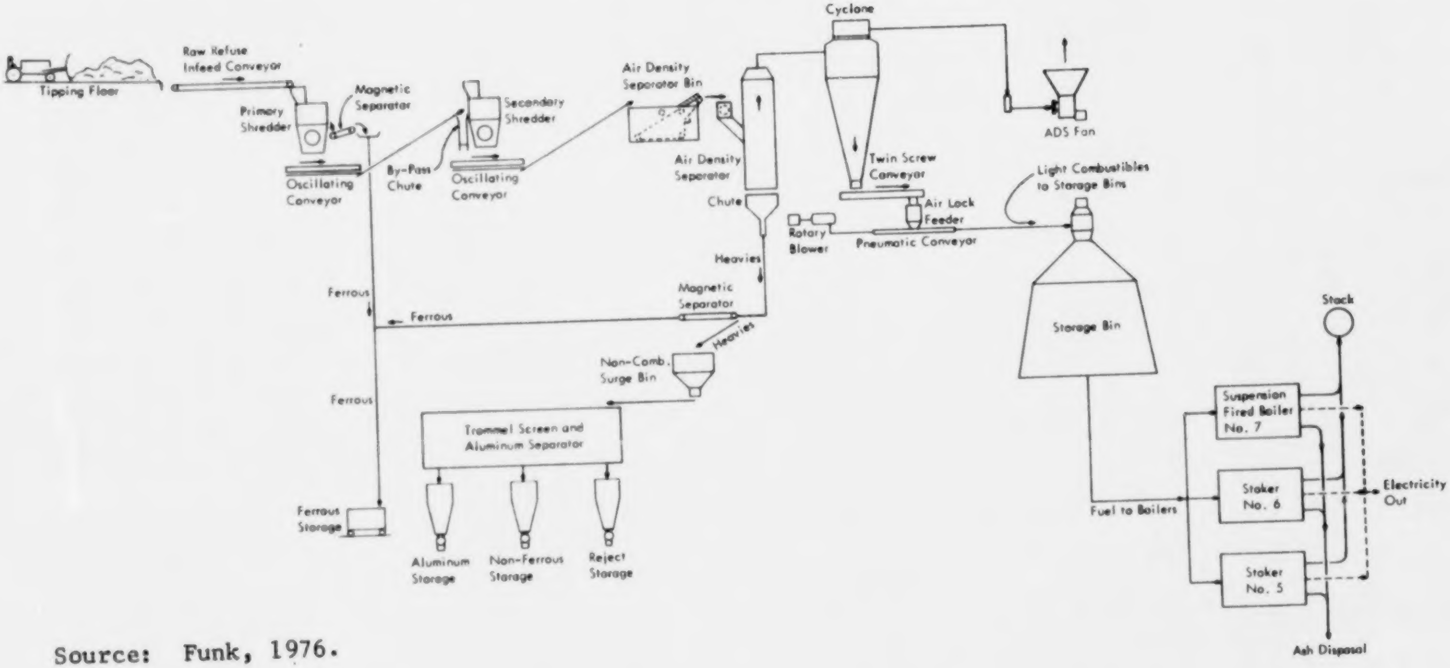
The entire system is housed in one building, with the receiving section walled off from the processing section. The plant receives mostly residential and industrial waste. Demolition materials, automobiiles, liquids and contaminated or hazardous wastes are not accepted. Additionally, items such as appliances and tires are removed from the waste stream prior to processing.

The processing plant has 30.5 meter by 48.8 meter fully-enclosed receiving and storage facility. Upon entering the facility, the trucks containing the raw refuse are weighed, after which they dump their contents onto the receiving floor. A front-end loader pushes the raw refuse onto a conveyor, which carries the material directly to the primary shredder. Intial shredding reduces the refuse to a maximum of about the 15 centimeter size.

After primary shredding, the refuse is subjected to magnetic separation for removal of ferrous metals, and then to a secondary shredding operation, which further reduces the particles to a monimal 2.54 centimeter size. The shredded refuse is then fed into a surge bin and then into an air classifier at a controlled rate. The light fraction leaving the air classifier goes into a cyclone separator which segregates the refuse from the airstream. The combustibles are then pneumatically conveyed, first to a storage bin and ultimately into the power plan boilers.

A flow diagram of the processing operations is shown in Figure 2.

The refuse-derived fuel is primarily used in the largest of the three boilers in the power plant. Four refuse fuel conveyor pipelines are connected to this boiler; however, normally, only two of the four lines are operated on diagonally opposite corners, with the other two for backup. The refuse fuel represents about 12 percent of the total fuel input to the boiler at maximum level; after a 5-year operation, it is anticipated that the percentage will be increased to 20 percent.


Tipping Floor
Raw Refuse Infeed Conveyor
Primary Shredder
Magnetic Separator
Oscillating Conveyor
By-Pass Chute
Secondary Shredder
Oscillating Conveyor
Air Density Separator Bin
Air Density Separator
Chute
Cyclone
ADS Fan
Twin Screw Conveyor
Air Lock Feeder
Rotary Blower
Pneumatic Conveyor
Light Combustibles to Storage Bins
Storage Bin
Heavies
Magnetic Separator
Ferrous
Ferrous
Ferrous
Heavies
Non-Comb. Surge Bin
Trommel Screen and Aluminum Separator
Ferrous Storage
Aluminum Storage
Non-Ferrous Storage
Reject Storage
Fuel to Boilers
Suspension Fired Boiler No. 7
Stoker No. 6
Stoker No. 5
Stack
Electricity Out
Ash Disposal

Source: Funk, 1976.

Figure 2. Flow diagram of Ames, Iowa plant.

Some unanticipated problem areas have been encountered in the operation of the plant: (1) dust accumulation, which creates a housekeeping problem as well as potential fire, explosion and health hazards; (2) jamming in the storage bin due to streching of the sweep bucket chain; (3) plugging of the pneumatic conveyors; (4) spillage of the MSW at the air classifier entrance; and (5) appreciably less throughput of the secondary shredder than originally anticipated.

Some testing and evaluation of the Ames facility is currently being conducted by a group from Iowa State University.* Although additional testing is possible, there is a potential problem relating to the layout of some of the unit operations, which inhibits access to input and output streams.

Baltimore, Maryland

The City of Baltimore facility was designed to convert refuse to steam through a gas pyrolysis system developed by the Monsanto Company in St. Louis. The facility was to operate at a capacity of 90.7 metric tons per hour, about 10 hours per day. The initial operation ran from January to September 1975, after which the plant was closed to correct several unexpected problems. Following completion of the modifications, operation was resumed, but technical problems have continued.

Raw refuse is dumped from the packer trucks into a large receiving bin and they conveyed to one of two horizontal shredders. The shredding operation produces a product with a nominal 10.2 centimeter shred size, which is then conveyed to the storage bin. The shredded refuse is removed from the bin by means of rotating buckets which deposit the portioned product onto a signle outfeed belt. This in turn feeds the waste into the pyrolysis kiln.

The kiln itself is 5.8 meters in diameter and about 30.5 meters long. It rotates at about two revolutions per minute and is lined with refractory material to keep the heat within the kiln and to protect the metal shell. The high heat necessayr to pyrolyze the waste is supplied by a portion of the waste itself and by a supplemental fuel (No. 2 heating oil). Steam is produced through the combustion of the resultant pyrolysis gases in an afterburner which creates the heat necessary to operate two waste-heat boilers. The steam is piped to an existing Baltimore Gas and Electric steam distribution system which heats and cools downtown buildings.

A flow diagram of the system appears in Figure 3.

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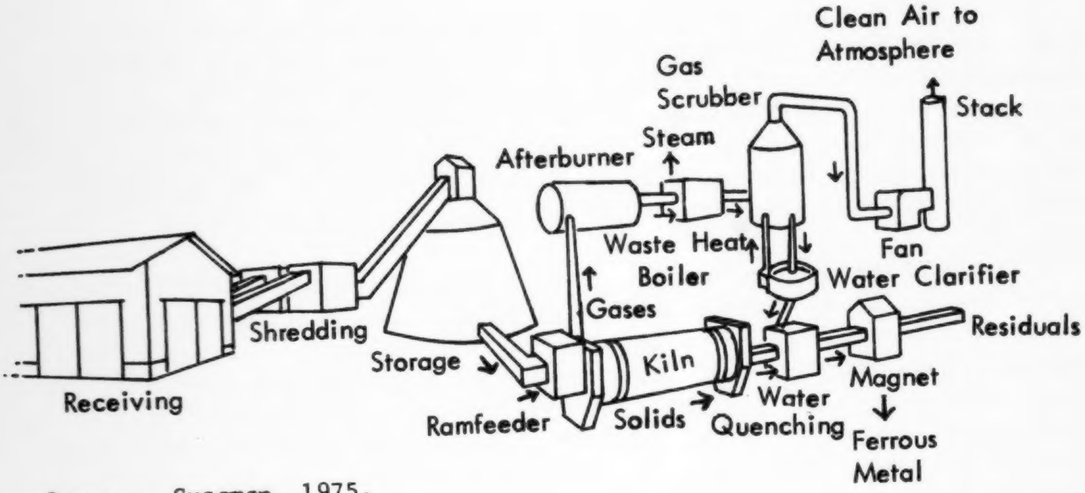
* The Ames tests are being jointly funded by the EPA and ERDA.


Clean Air to
Atmosphere
Gas
Scrubber
Stack
Steam
Afterburner
Waste Heat
Boiler
Fan
Water Clarifier
Gases
Shredding
Storage
Kiln
Residuals
Magnet
Receiving
Ramfeeder
Solids
Water
Quenching
Ferrous
Metal

Source: Sussman, 1975.

Figure 3. Baltimore plant flow diagram.

The Baltimore system has experienced several significant problems, which caused shutdowns: (1) the residue from the kiln has had a tendency to slag, indicating that the glass particles in the refuse are being metled by the high temperatures in the kiln; (2) additionally, the high pyrolysis temperatures have caused failures of the kiln's refactory lining; and (3) there have been excessive particulates in the exhaust gases, which the system's wet scrubbers have not been able to remove. The installation of electrostatic precipitators, should alleviate the last problem. Since these problems were not encountered in the pilot plant and therefore not anticipated at full-scale operation, numerous modifications in the design have been necessary.

Two additional problems were encountered relative to processing: (1) an explosion occured in one of the shredders during operation, causing damage to the shredder itself as well as to the building; (2) feed problems have been experienced in removal of the shredded waste from the storage bin.

The plant is not available for tests because of operational problems.

Baltimore County, Maryland

The Baltimore County facility is located in Cockeysville, Maryland. Designed by Teledyne National, the system produces refuse-derviced fuel to be used in bark furnace, cement kiln, and possibly other applications, and also recovers ferrous metals. It has a capacity of 90.7 metric tons per hour and currently processes approximately 455 metric tons per day.

The facility utilizes receiving pits rather than a signle receiving room. Trucks back into the individual pits and dump the waste, which is subsequently pushed onto a conveyor belt by hydraulic rams. The refuse is then conveyed directly into one of two horizontal shredders, under the control of an operator who regulates material flow from an elevated control room. The control system is a computerized design by Teledyne. The shredders reduce the waste to a maximum 7.6 to 10.2 centimeter shred size.

The shredded refuse is conveyed to a belt magnet for removal of ferrous metal, after which it is fed into two air classifiers in series. The first separates the MSW into a combustible fraction and a heavy fraction (metals, glass, etc.). The second classifier separates the combustible fraction into two grades of RDF fuels.* Finally, the light fraction is compacted and transported to the user sites. A trommel screen and other equipment have recently been added for removal of glass and aluminum from the heavy fraction. A bag house is used to clean up airborne discharges from the shredders and air classifiers.

A flow diagram of the system appears in Figure 4.

Baltimore County encountered some back pressure problems in the air classifiers, caused by the cyclone separators. Teledyne designed special rotary airlocks to correct this problem. The RDF system is operational at the present time, and the RDF has been used as fuel for process heat at a paper manufacturing plant.

The Baltimore County facility has been used as a test site for this project.**

South Charleston, West Virginia

Designed and operated by the Union Carbide Company, the South Charleston facility converts refuse into a gas by means of a patented pyrolysis process called the PUROX system. The facility has a capacity of 181.8 metric tons per day, and is normally operated 24 hours per day. The plant has been operational since 1974.

The South Charleston facility has a separate storage building where the waste is intially dumped and stacked by a front-end loader. The loader then picks up the stored waste and is weighed on a platform scale, after which it dumps the refuse onto a conveyor leading to the shredder. Prior to entering the shredder, the waste is subjected to manual sorting to remove tires and other materials which could cause stalling or jamming of the shredder.

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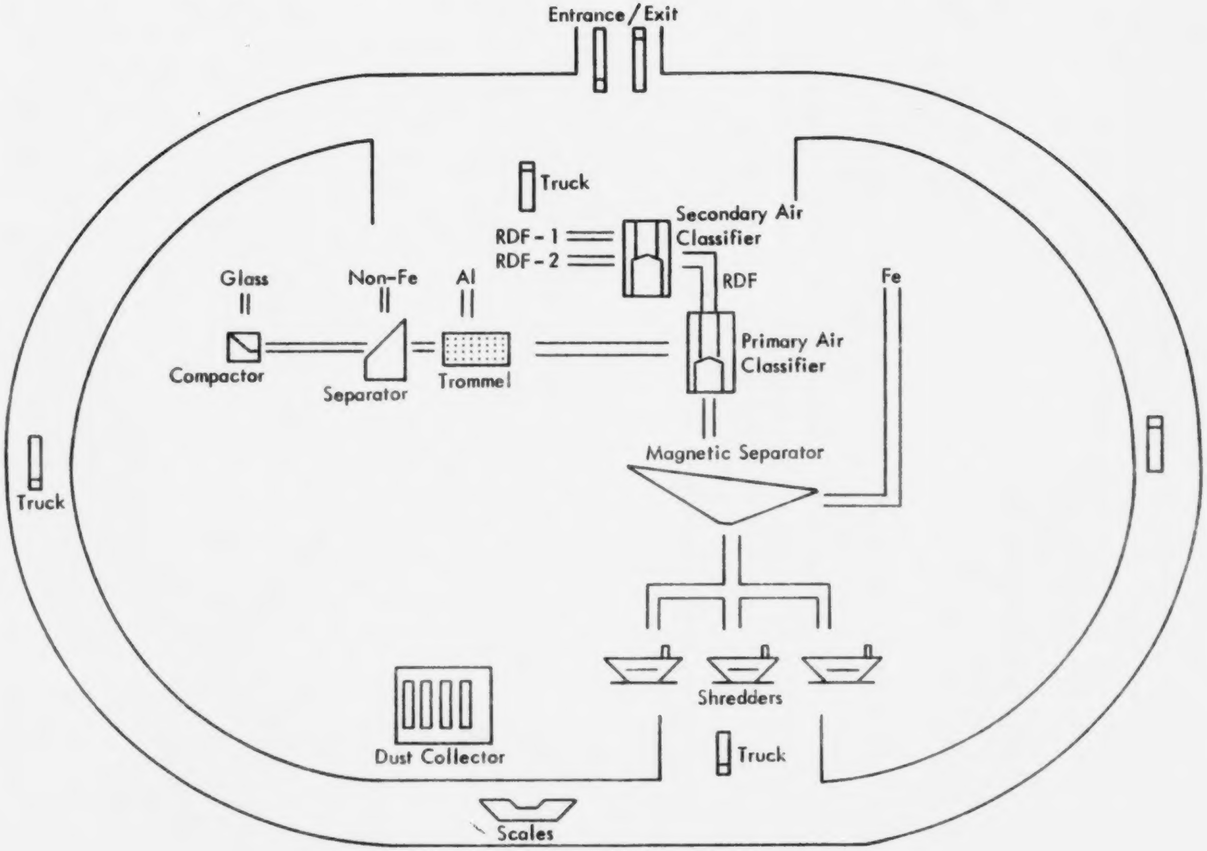
* The second air classifier is not normally used.

** Tests conducted at the Baltimore County plant are reported in Volume II.


Entrance/Exit
Truck
RDF-1
RDF-2
Secondary Air Classifier
RDF
Glass
Non-Fe
Al
Fe
Compactor
Separator
Trommel
Primary Air Classifier
Magnetic Separator
Truck
Shredders
Dust Collector
Truck
Scales

Source: McKewen, 1976.

Figure 4. Flow diagram of the Baltimore County, Maryland, facility.

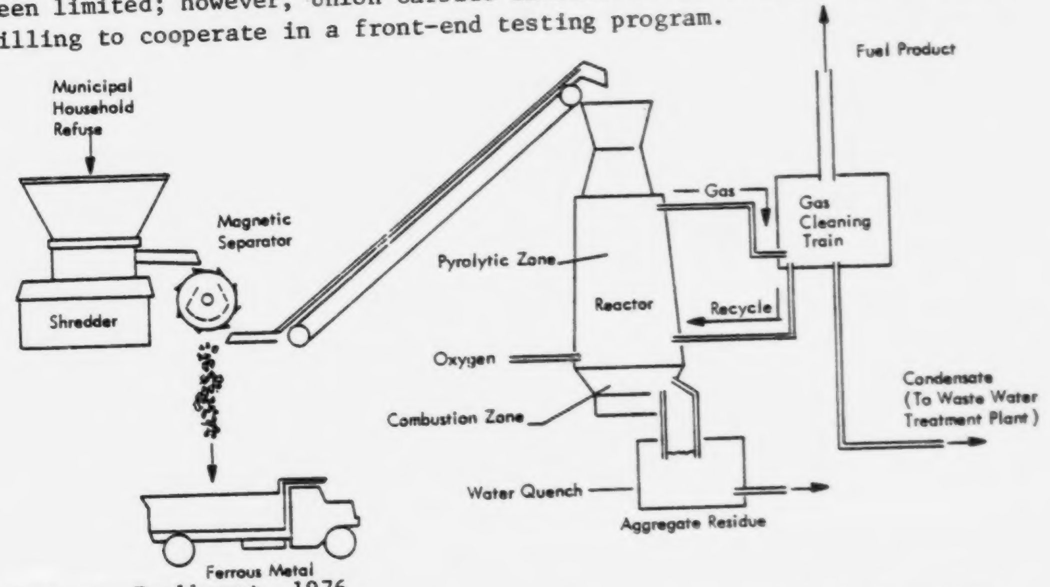
The vertical shredder produces a nominal 7.6 centimeter shred size. Following this initial refinement, the refuse is then fed under a drum magnet to remove the ferrous metals, and then conveyed to a feed hopper at the top of the vertical pyrolysis reactor. The material is fed into the top of the reactor by two 14-inch hydraulic rams and passes into the lower zone of the reactor. Oxygen is simultaneously fed into the reactor at a ratio of about 20 percent by weight of the refuse. Noncombustibles are metled at the 2500° temperature of the lower zone, to produce a fine-grain slag (about 17 percent by weight of the input waste).

The gasses generated in the reactor are cleaned by water spray and an electrostatic precipitator and are currently being burned for disposal. The gas heating value is about 13,034.5 kilojoules per cubic meter.

A flow diagram of the South Charleston system appears in Figure 5.

The main problem concerning processing reported by Union Carbide representatives relates to the magnetic separation system. A considerable amount of paper and plastic is being picked up along with the ferrous fraction. This is a single drum magnet located 90 degrees to the shredder take-off conveyor. The system operators recognize that this magnet installation is not designed for best efficiency.

The emphasis at the South Charleston facility is on the pyrolysis system rather than the initial processing operations; it is a pilot plant. As a result, the expenditure of resources on the processing equipment has been limited; however, Union Carbide indicated that they probably would be willing to cooperate in a front-end testing program.


Municipal Household Refuse
Magnetic Separator
Shredder
Ferrous Metal
Fuel Product
Gas
Gas Cleaning Train
Pyrolytic Zone
Reactor
Recycle
Oxygen
Combustion Zone
Condensate (To Waste Water Treatment Plant)
Water Quench
Aggregate Residue

Source: Parkhurst, 1976.

Figure 5. Flow diagram (South) Charleston pyrolysis facility.

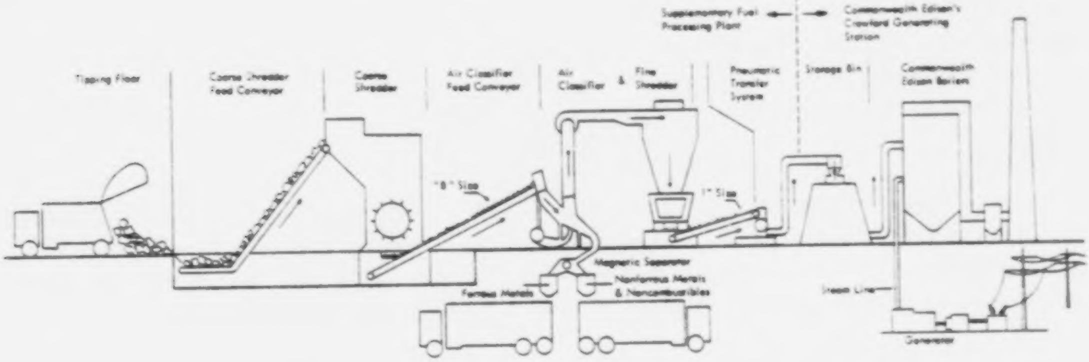
Chicago, Illinois

The Chicago facility was designed as a joint venture by the Ralph M. Parsons Company of Pasadena, California, and Consoer-Townsend and Associates of Chicago. It is an RDF system which also recovers ferrous metals, designed to operate at a capacity of 145 metric tons per hour (900 metric tones per day). The plant is currently in the shakedown phase.

The facility has a double-line processing system, fed by two apron conveyors linking the common receiving room to the primary horizontal hammermills. After primary shredding, shred size is specified to be 95 percent 20.3 centimeters or less. Following primary shredding, the material is conveyed to an air classifier, and the light fraction is subjected to secondary shredding, specified as 95 percent 3.8 centimeters or less.

The shredded light fraction is then pneumatically conveyed to two storage silos at the power generating plant, owned by Commonwealth Edison, where it is fired as a supplementary fuel. Dust control is provided by dust hoods and a vacuum system which remove the dust from the plant, directing it through a baghouse filter prior to discharge into the atmosphere. Fire protection devices are also incorporated into the plant design.

A flow diagram of the Chicago RDF system appears in Figure 6.


Supplementary Fuel Processing Plant
Commonwealth Edison's Crawford Generating Station
Tipping Floor
Coarse Shredder Feed Conveyor
Coarse Shredder
Air Classifier Feed Conveyor
Air Classifier
&
Fine Shredder
Pneumatic Transfer System
Storage Bin
Commonwealth Edison Boilers
"8" Size
1" Size
Magnetic Separator
Ferrous Metals
Nonferrous Metals & Noncombustibles
Steam Line
Generator

Source: Chicago-summary of solid waste disposal systems study.

Figure 6. Flow diagram of Chicago facility.

The Chicago facility was originally scheduled to begin operations in laste 1976, but problems with the secondary shredders resulted in postponement of startup. The plan is presently in partial operation due to problems with the secondary shredder and air classifier.

The Chicago plant will be tested under a separate EPA test program presently being negotiated.

East Bridgewater, Massachusetts

The East Bridgewater plant produces a proprietary finely shredded refuse-derived fuel product called Eco-Fuel II. Designed by Combusion Equipment Associates, Inc., in conjuction with the Arthur D. Little firm, the East Bridgewater plant began production in December 1976. In addition to the production of Eco-Fuel II, the facility recovers ferrous metals. It has a capacity of 22.7 metric tons per hour based on 24 hours per day.

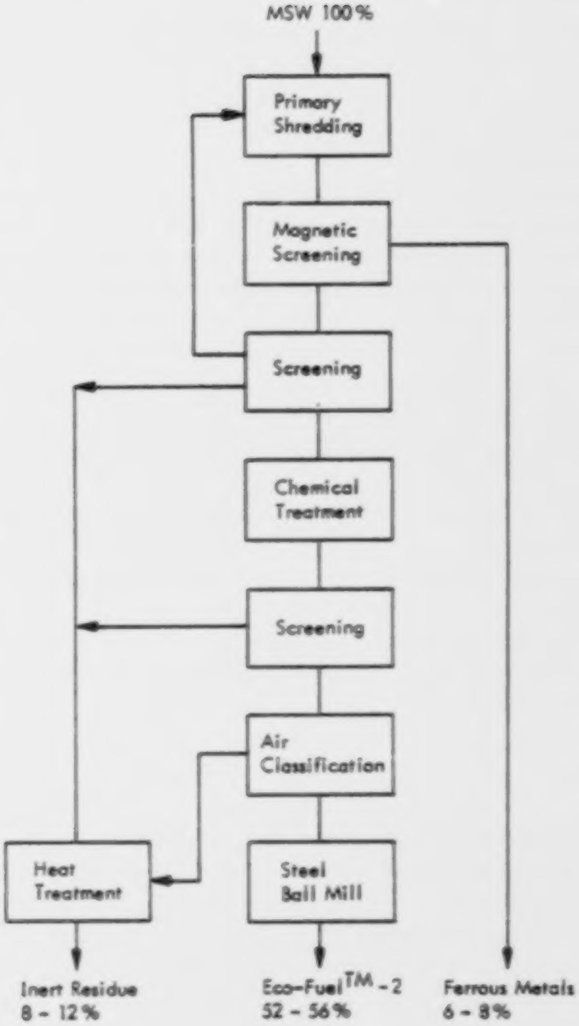
As shown in Figure 7, the processing system begins with a primary shredding process which utilizes a flail-mill type of shredder. Following shredding, the refuse is conveyed to a magnetic separator and then screened and classified into three fractions: an oversized fraction, which is recycled through the primary shredder; a fine fraction composed mainly of glass and dirt; and a shredded MSW fraction. The shredded portion is chemically treated by a process which helps to reduce it to a fine particle size but does not change its chemical composition. Finally, the product is passed through a ball mill for actual size reduction, and then screened and air classified to create the Eco-Fuel II.

The East Bridgewater plant has been previously operational, first in the incineration of MSW and then for the production of a coarse-shredded RDF product called Eco-Fuel I. Problems with the present system have included general problems with the control system, because of its sophistication and complexity. An explosion occurred in the plant, resulting in the death of an employee.

It would appear unlikely that EPA-sponsored tests could be done at the East Bridgewater plant. The system operators feel that testing would interfere with normal operations; however, they might be interested in having tests done at their Carter-Day test facilities in Minneapolis, Minnesota.

El Cajon, California

The El Cajon facility, designed by Occidental Research Corporation, utilizes a pyrolysis system to convert MSW into a liquid fuel product. The processing plang will have a capacity of 181.8 metric tons per day. Currently, the processing equipment is being tested; the plant is partially operational.


MSW 100%
Primary Shredding
Magnetic Screening
Screening
Chemical Treatment
Screening
Air Classification
Heat Treatment
Steel Ball Mill
Inert Residue 8 - 12%
Eco-Fuel^{TM}-2 52 - 56%
Ferrous Metals 6 - 8%

Source: Combustion Equipment Associates, Inc. and Arthur D. Little, Inc.

Figure 7. Flow diagram of East Bridgewater plant.

El Cajon receives only residential and commercial waste, which are dumped onto the receiving building following weighing of the trucks. A front-end loader then pushes the MSW onto a depressed flight conveyor; the conveyor speed is controlled by the control room operator.

As shown in Figure 8, the initial processing step is shredding, which is performed by a horizontal shredder with 7.6 centimeters by 12.7 centimeters grate opening. The large grate size was employed to handle large or hard pieces of refuse in the shredder. From the shredder, the refuse is transported via pan conveyor to a belt conveyor equipped with a belt magnet for ferrous removal. The belt conveyor then carries the MSW into a center-post rotating conveyor and deposits it in the main storage room. From there it is transported into a small storage bin. The MSW is discharged from the small bin by a linked-chain conveyor; a set of rotating blades fluff the waste before it moves onto the belt conveyor leading to the 10-stage zig-zag air classifier. The light fractions from the air classifier are then conveyed to a rotating drier which is heated by gases from the pyrolysis reactor reactor. Finally, the dried waste is screened to remove the fines and is reshredded to produce a fine fluff necessary for the pyrolysis unit. All equipment which generates dust is equipped with a baghouse filter system.

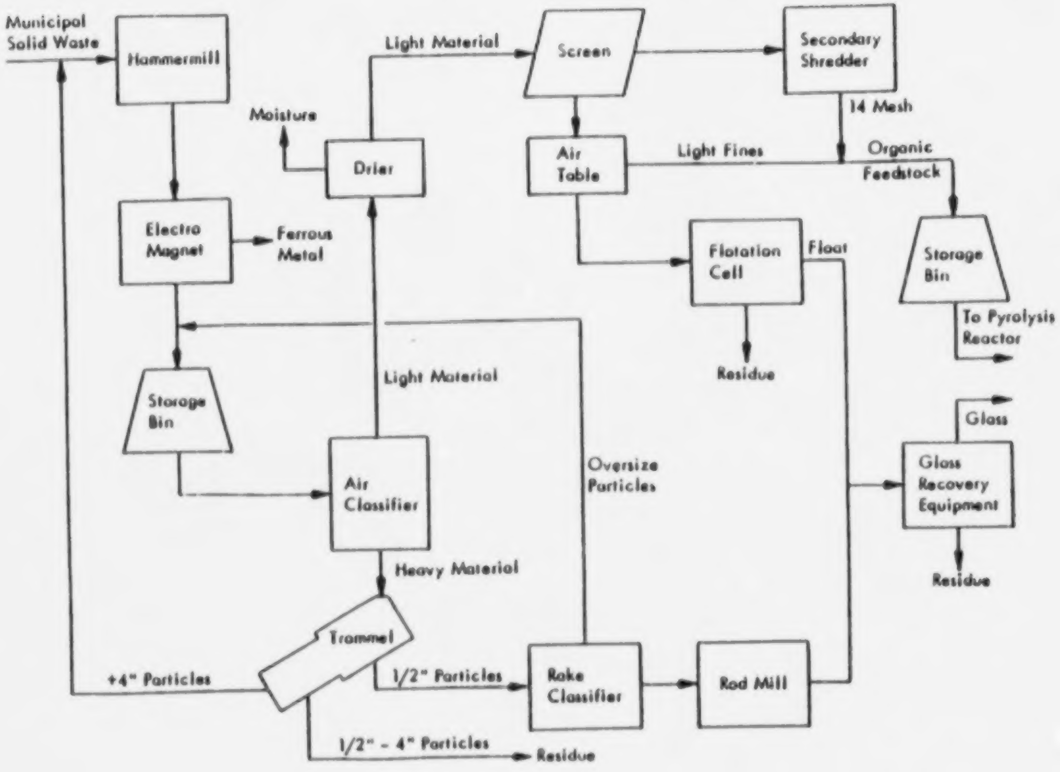
Front end equipment is being tested. Initial problems have been encountered concerning (1) the proper speed for the belt conveyors and (2) jamming of waste around the head pulley of the conveyors.

This plant is being tested under a separate EPA-OSWMP contract. Any additional tests would have to be integrated with the present test plans.

Milwaukee, Wisconsin

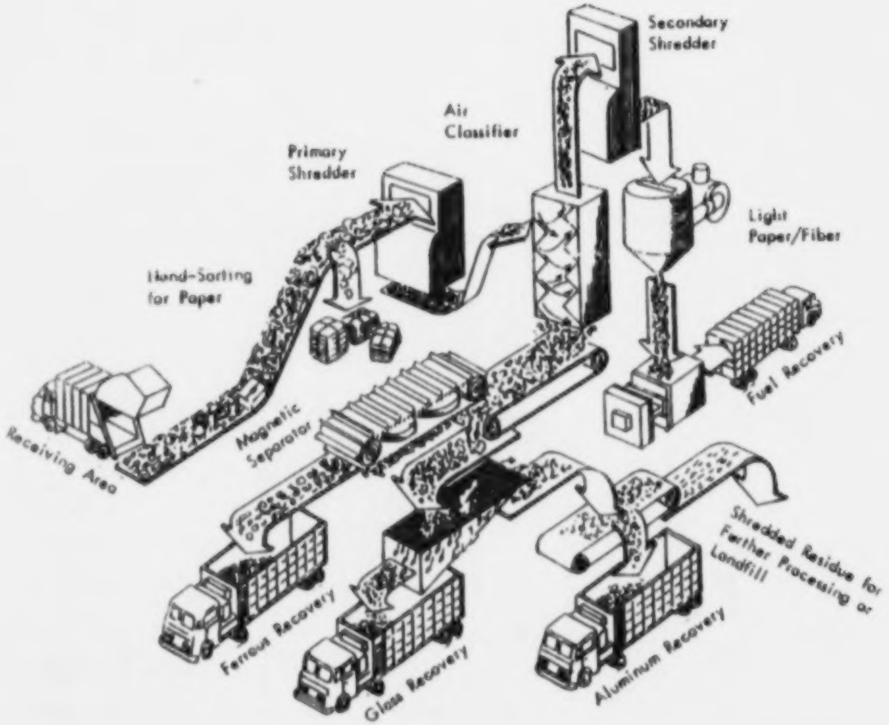
Owned, designed and operated by Americology, a division of American Can Company, the Milwaukee plant started operation in 1977. When full operational, the facility will have a capacity of 136.4 metric tons per hour and is expected to operate 8 hours per day. It will produce RDF, as well as recover ferrous metals, aluminum and glassy aggregate. The RDF will be used to fire boilers in the Oak Creek plant of Wisconsin Electric Power Company.

The flow diagram of the processing system is shown in Figure 9. As indicated, paper is hand-sorted from the incoming refuse prior to shredding. After leaving the primary shredder, the material is air-classified, and the light fraction processed through the secondary shredder. Finally, the material will be transported into a storage bin, discharged into trucks and hauled to the power plant. Some equipment changes are presently being made, primarily the additiona of magnetic separators and services to provide a cleaner fuel product.


Municipal Solid Waste
Hammermill
Electro Magnet
Ferrous Metal
Storage Bin
Air Classifier
Light Material
Heavy Material
Drier
Moisture
Light Material
Screen
Secondary Shredder
14 Mesh
Air Table
Light Fines
Organic Feedstock
Storage Bin
To Pyrolysis Reactor
Flotation Cell
Residue
Float
Glass Recovery Equipment
Glass
Residue
Oversize Particles
Trommel
+4" Particles
1/2" Particles
1/2" - 4" Particles
Residue
Rake Classifier
Rod Mill

Source: Levy, 1975.

Figure 8. Flow diagram of El Cajon facility.


Secondary
Shredder
Air
Classifier
Primary
Shredder
Light
Paper/Fiber
Hand-Sorting
for Paper
Fuel Recovery
Receiving Area
Magnetic
Separator
Shredded Residue for
Further Processing or
Landfill
Ferrous Recovery
Glass Recovery
Aluminum Recovery

Source: Americology

Figure 9. Flow diagram of Milwaukee plant

Accessibility to the Milwaukee plant for testing purposes is somewhat doubtful. Americology, under contract to dispose of Milwaukee's solid waste, is reluctant to permit tests of the plant by an outside organization at this time. However, Americology representatives have indicated willingness to discuss the possibility at a later date.

Washington, D. C.

This is a pilot plant test facility which can operate at a capacity of 22.7 metric tons per hour. In addition to the production of RDF and pellets, the facility has been used to recover ferrous metals, aluminum, and glass. It has been operational since 1972 under the management of the National Center for Resource Recovery.

The processing system incorporates a shredder, which discharges into a vibrating air classifier. The light fraction from the air classifier goes into a cyclone separator or segregation of RDF from the air stream. Finally, the RDF is pneumatically conveyed into the incinerator pit. NCRR has recently installed a secondary shredder and a pelletizer to extrude the light fraction into pellets. A flow diagram of the system appears in Figure 10.

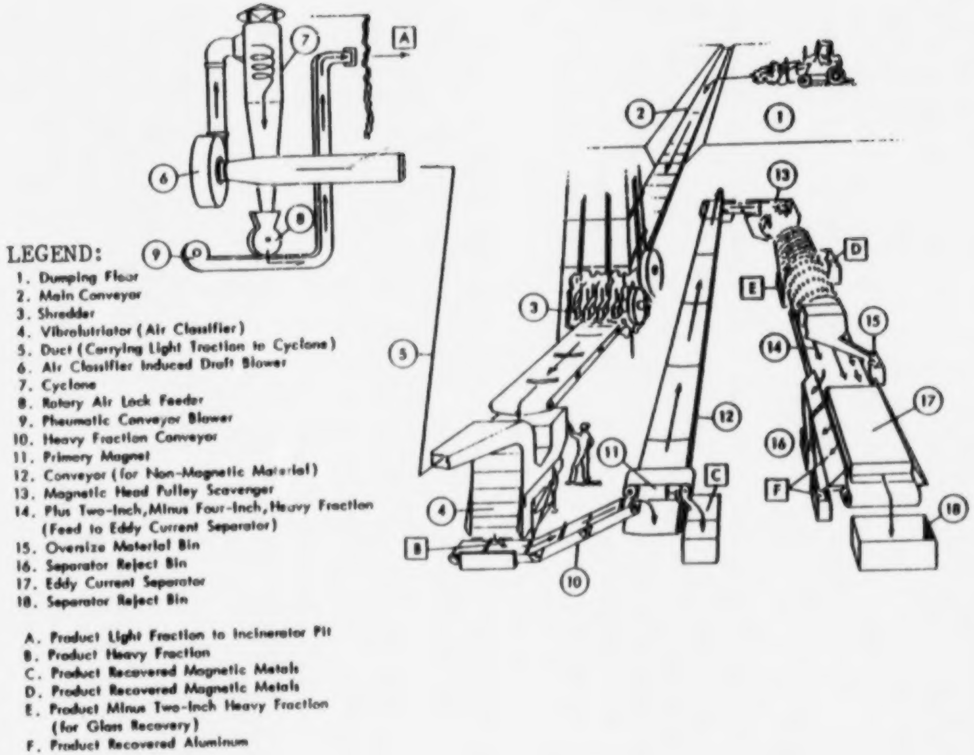
The NCRR system has experienced some problems with the air classifier; however, details have not been published.

Since the NCRR system is a testing facility, it is a potential site for tests requiring controlled operating conditions.

Palmer Township, Pennsylvania

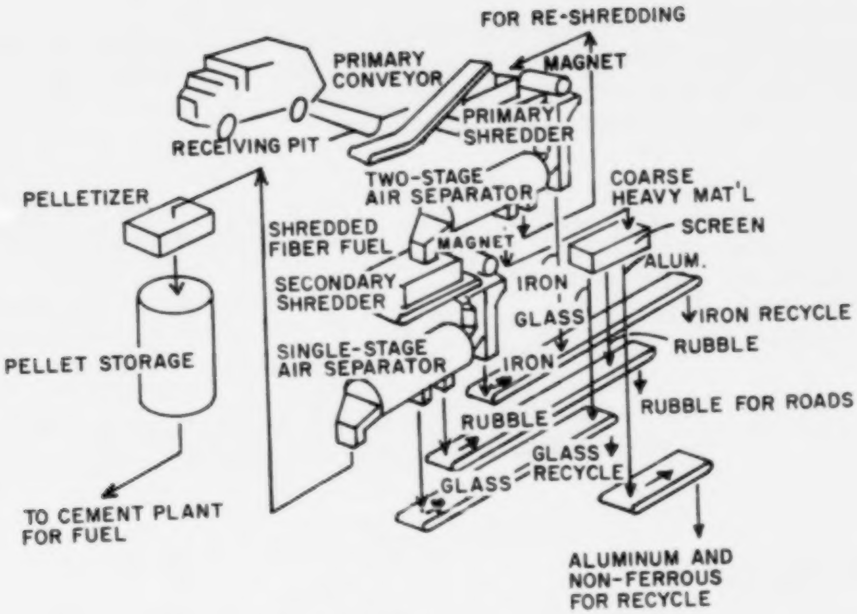
The Palmer facility, is designed to process MSW to produce a pelletized RDF product for use in cement kilns. The plant, which is a joint interest of the Palmer Township Board of Supervisors and the local cement industry, is designed to Elo and Rhodes Consulting Engineers of Easton, Pennsylvania. In addition to the production of fuel, the facility will recover ferrous metals, aluminum and glass. It is designed to operate at a capacity of 18.2 metric tons per hour.

As shown in Figure 11, the refuse is initially dumped into a receiving pit, from which it is conveyed into a totally enclosed system designed to avoid dust and odor. The refuse is first ground in a primary shredder into a nominal 7.6 centimeter shred size. A magnetic drum removes the ferrour metals, and the refuse stream is then processed through two air separators. The first removes the lighter materials which then pass into a


A
1
2
13
D
E
3
15
5
14
6
7
8
9
12
17
16
11
C
F
4
18
B
10
LEGEND:
1. Dumping Floor
2. Main Conveyor
3. Shredder
4. Vibrolutriator (Air Classifier)
5. Duct (Carrying Light Traction to Cyclone)
6. Air Classifier Induced Draft Blower
7. Cyclone
8. Rotary Air Lock Feeder
9. Pneumatic Conveyor Blower
10. Heavy Fraction Conveyor
11. Primary Magnet
12. Conveyor (for Non-Magnetic Material)
13. Magnetic Head Pulley Scavenger
14. Plus Two-Inch, Minus Four-Inch, Heavy Fraction (Feed to Eddy Current Separator)
15. Oversize Material Bin
16. Separator Reject Bin
17. Eddy Current Separator
18. Separator Reject Bin
A. Product Light Fraction to Incinerator Pit
B. Product Heavy Fraction
C. Product Recovered Magnetic Metals
D. Product Recovered Magnetic Metals
E. Product Minus Two-Inch Heavy Fraction (for Glass Recovery)
F. Product Recovered Aluminum

Source: Alter and Natof, 1976.

Figure 10. Flow diagram of NCRR facility.


FOR RE-SHREDDING
PRIMARY CONVEYOR
MAGNET
PRIMARY SHREDDER
RECEIVING PIT
TWO-STAGE AIR SEPARATOR
COARSE HEAVY MAT'L
PELLETIZER
SHREDDED FIBER FUEL
MAGNET
SCREEN
ALUM.
SECONDARY SHREDDER
IRON
GLASS
IRON RECYCLE
PELLET STORAGE
SINGLE-STAGE AIR SEPARATOR
IRON
RUBBLE
RUBBLE
RUBBLE FOR ROADS
GLASS RECYCLE
GLASS
TO CEMENT PLANT FOR FUEL
ALUMINUM AND NON-FERROUS FOR RECYCLE

Source: Elo and Rhodes, 1976.

Figure 11. Flow diagram of Palmer Township facility.

air separators for further segregation and into a cyclone for separation of the RDF fraction from the airstream. The material is then passed through a secondary shredder. At this stage, the fraction is less than 2.54 centimeters in size. A second and final air separation takes out residual glass and rubble. Following screening, a light fraction is densified to form the compacted fuel pellets, which are then collected in a storage bin and held until they are transported to the kilns.

There are several reservations about using Palmer Township as a test site: (1) the facility will operate at a relatively small scale, and (2) it has been difficutl to obtain information about the facility from local officials, making it difficult to evaluate the potential of this plant for tests.

Pompano Beach, Florida

The Pompano Beach plant, dedicated in May 1978 is a "proof of process" system funded by the Department of Energy (DOE). The facility is designed to produce a methane-rich gas by anaerobic digestion of MSW coupled with sewage sludge. Additionally, ferrous metals and paper can be recovered. The plant will have an initial capacity of 1.9 to 3.8 metric tons per hour and is expected to operate 24 hours per day.

Processing of the MSW first involves primary shredding and magnetic separation, both of which will take place in the "shredding facility." The stream will then be conveyed to the "processing facility," where it will pass through a storage and retrieval system, a trommel, a secondary shredder, and an air classifier. Following processing, the stream will be conveyed into the digestor system. A flow diagram of the system appears in Figure 12.

DOE has indicated that the Pompano Beach facility will be made available to EPA for environemntal testing, and data will also be collected on process parameters.

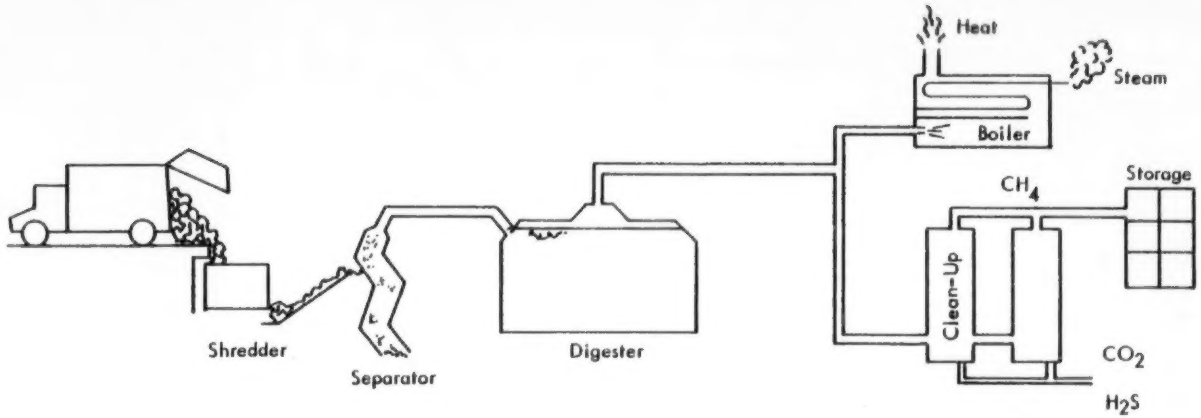
Riverside, California

Designed by Pyrolysis Systems, Inc. and owned by the City of Riverside, California, the facility will initially serve as a pilot plant to demonstrate process feasibility. The process, called the X-50 Pyrolysis System, will produce a low Btu gas which will be converted in the plant to electrical energy by internal combustion engine driven generators. The system has been developed for installation in combinations of 45.4 metric tons per day modules, with capacities ranging from 45.4 to 454.5 metric tons per day. The first-phase Riverside plant will have a capacity of 1.9 metric tons per hour, and will operate 24 hours per day; in the planned second phase, capacity will be increased to 11.4 metric tons per hour, also based on a 24-hou operation.

As shown in Figure 13, the only refinement process to be utilized in the system is shredding. Ancillary operations include the receiving facility, a unique live-bottom inverted storage bin designed to prevent bridging of the MSW, conveyors and a simple control system. Following retrieval from the storage bin, the MSW is pyrolyzed at a temperature of 1500^{o} F., and surplus pyrolytic gases are converted into electricity by a natural gas internal combustion engine/generator.

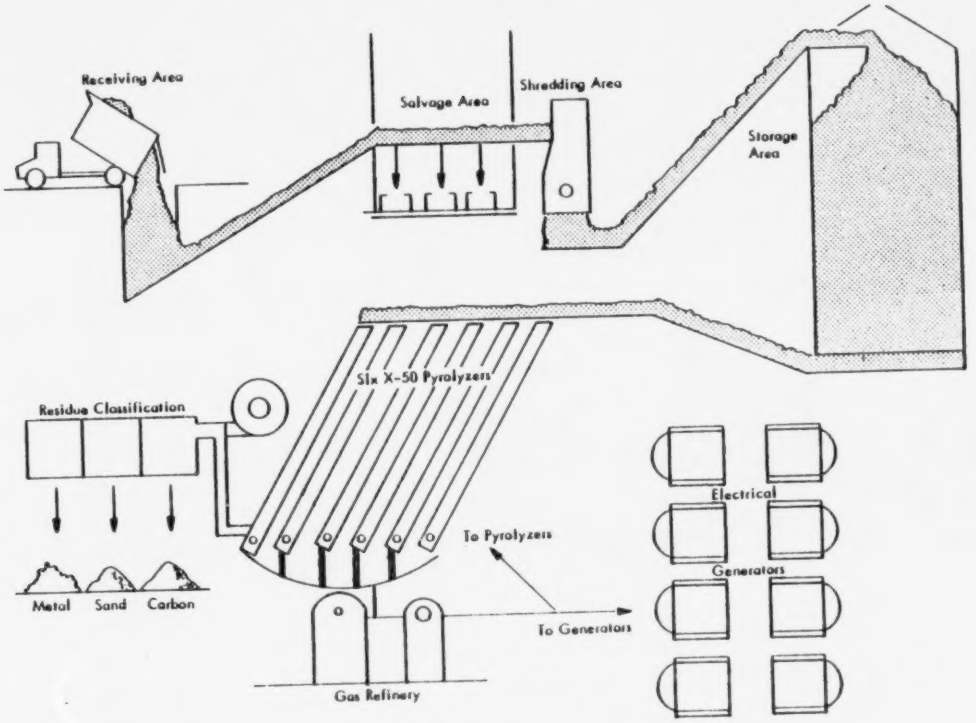
The pilot plant at Riverside is the first test facility for the X-50 process. The designers have patents on some of the devices and equipment but no viable performance data are available.

Full scale testing at Riverside does not seem feasible at this time, since this is the first pilto plant and it is a small-scale facility. Given the usualy problems encountered in intial process testing, it would appear unlikely that the facility would ve available to test the processing equipment.


Heat
Steam
Boiler
CH_4
Storage
Clean-Up
CO_2
H_2S
Shredder
Separator
Digester

Source: Energy Research and Development Administration (ERDA)

Figure 12. Flow diagram of Pompano Beach facility.


Receiving Area
Salvage Area
Shredding Area
Storage Area
Six X-50 Pyrolyzers
Residue Classification
Metal
Sand
Carbon
To Pyrolyzers
To Generators
Electrical
Generators
Gas Refinery

Source: Pyrolysis Systems, Inc.

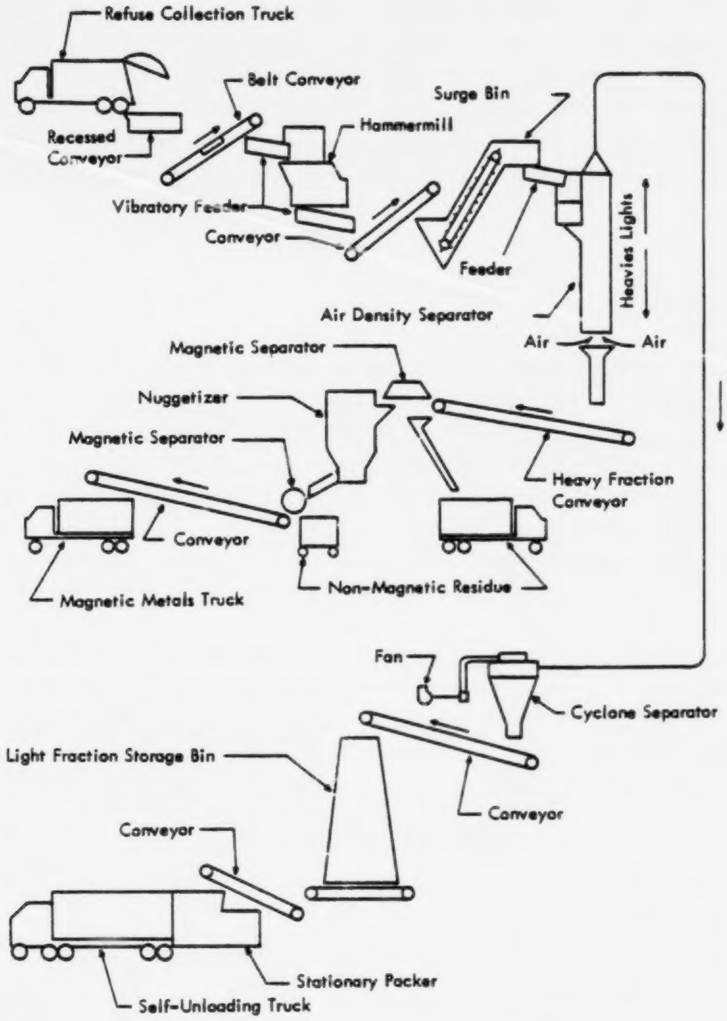
Figure 13. Flow diagram of Riverside facility.

St. Louis, Missouri

The St. Louis facility described here in the demonstration facility which was operational from 1972-1976 (part-time operation). The demonstration facility has a capacity of 32 metric tons per hour. It produces RDF and recovers ferrous metals. The system designer is Horner and Shifrin of St. Louis, The plant is presently inactive.

The St. Louis demonstration facility utilizes only primary shredding, followed by air classification. Magnetic separation takes place after air classification on the heavy fraction only, and does not therefore affect the energy product. The light fraction is passed through a cyclone separator, conveyed to a storage bin and then transported to the Union Electric power plant for use as a supplementary fuel in the boilers. A flow diagram of the system appears in Figure 14.

The St. Louis plant was designed primarily to demonstrate the feasibility of processing MSW into a supplementary fuel for power plant boilers. As a first generation plant, it has also been used to collect initial experience on the operation of a waste-to-energy stystem. Some of


Refuse Collection Truck
Belt Conveyor
Surge Bin
Hammermill
Recessed Conveyor
Vibratory Feeder
Conveyor
Feeder
Heavies
Lights
Air Density Separator
Air
Air
Magnetic Separator
Nuggetizer
Magnetic Separator
Heavy Fraction Conveyor
Conveyor
Magnetic Metals Truck
Non-Magnetic Residue
Fan
Cyclone Separator
Light Fraction Storage Bin
Conveyor
Conveyor
Stationary Packer
Self-Unloading Truck

Source: MRI, 1975

Figure 14. Processing flow diagram-St. Louis (demonstration plant).

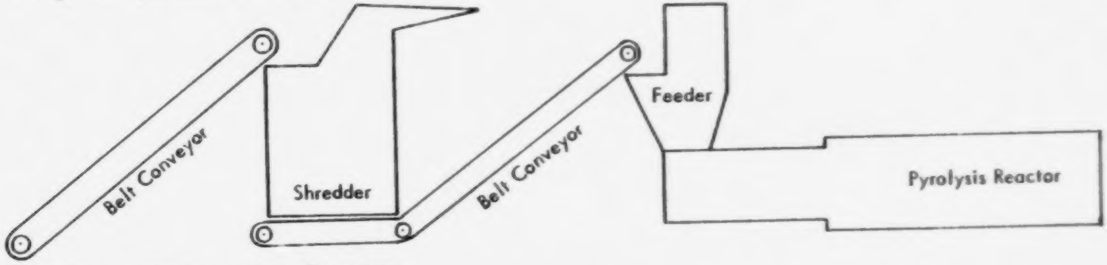
the important findings relative to processing equipment were (1) an air classifier is effective in removing the nonburnables from the MSW, (2) there is considerable wear of the hammermill hammers, (3) there is considerable wear at the bends in pneumatic conveyors, (4) the emmission from the air classifier contains a considerable amount of particulates, (5) there are high levels of noise in and around the processing plant, and (6) there have been fires in the control room, hammermill feed belt and storage bins.

The St. Louis demonstration pland has been used by MRI (under a separate contract) to evaluate pollution aspects (bacteria and virus) of the waste-to-energy process. The plant may be available to conduct other tests which may be appropriate for this plant. However, this is a first generation plant, lacking many of the refinements of new plants, so that data collected at this plant many not be representative of the latest stat state of the art

Southgate, California

The Southgage facility utilizes a pyrolysis system to extract fuel oil and gas from MSW. The pyrolysis concept was originially developed by Due Engineering Company of Irvine, California, who subsequently sold the manufacturing and marketing rights to the Enterprise Company of Santa Ana, California. Enterprise has incorporated its own processing equipment into the pyrolysis process. Capacity at Southgate is 45.5 metric tons per day. Following thorouth testing and evaluation, the plant is to be shipped to New York (to a client whose name is confidential).

The refuse shredded in a double-shaft horizontal hammermill designed by Enterprise specifically for processing MSW; however, the shredder has only been tested on small quantities of waste to date. Following shredding, the MSW is conveyed directly to the pyrolysis reactor. A flow diagram appears in Figure 15.



Source: Enterprise Company.

Figure 15. Flow diagram of Southgate facility.

PROCESSING EQUIPMENT

Waste-to-energy processing equipment performs a series of refinement operations, which transform the MSW into fuel or fuel feedstock. In the following two sections of the report, the processing equipment used in waste-to-energy systems is divided into (1) unit equipment, and (2) supplementary equipment. Unit equipment is defined as equipment which changes the character of the waste stream. Unit equipment includes shredders, magnetic separators, air classifiers, screens, dryers and densifiers. Supplementary equipment is defined as equipment which aids in the processing of MSW but does not change the character of the waste stream. Supplementary equipment includes receiving facilities, conveyors, storage and retrieval bins, electrical controls, dust controls, and fire and explosion controls. Within each category of equipment there are various types; e.g., the category "shredder" incorporates vertical hammermills, horizontal hammermills, ring mills, grinders, flail mills, and ball mills.

Althrough the unit equipment and supplementary equipment are discussed separately, it is important to remember that various combinations of these pieces of equipment make up a processing system. There is an important interrelationship between the various pieces of equipment in the system, with each piece directly affecting the performance of the others, as well as the entire system.

The state of the art of processing equipment for waste-to-energy systems will be discussed in the following manner:

1. Description of the function of each unit operation and supplementary operation;

2. Enumeration of the types of equipment for each unit operation and supplementary operation, and a description of the technical aspects of each type of equipment; and

3. A comparison of the different types of equipment and experience with this equipment on MSW.

Summary tables of data received from equipment manufacturers are provided in Appendix C.

Shredders

Function: Shredders are machines used to reduce the size of raw MSW. Shredding the raw MSW has the following desirable effects in waste-to-energy systems: (1) the waste is made more homogenous, (2) the volume is reduced, (3) separation of the noncombustibles from the combustibles is made easier, and (4) waste-derived fuel or feedstock is sized so that it can readily burn in power plant boilers or be converted into liquids or gases in pyrolysis reactors.

Primary shredders are used to initially reduce the incoming raw MSW; secondary shredders are used to further reduce the size of the output product from the primary shredder. All of the waste-to-energy systems investigated in this study use a prijary shredder, and most use a secondary shredder.

Description: The most common type of shredder presently used both as a primary and secondary shredder, for waste-to-energy systems is the hammermill. A hammermill consists of a central rotor with hammers prvoted to the rotor circumference. The rotor and hammers are enclosed in a heavy-duty housing. The housing may be lined with hard metal members, and some have stationary breaker plates or cutter bars mounted inside the housing. The incoming waste is reduced in size by being beaten and torn by the rotating hammers.

There are two basic types of hammermills--the horizontal shaft type and the vertical shaft type. In the first type, shown in Figure 16, the rotor shaft is mounted in a horizontal position and is supported on both ends with bearings. Input is from the tope and the material flows through the machine by gravity perpendicular to the shaft and exits out the bottom. Most horizontal hammermills have a curved grate placed across the outlet under the swinging hammers. The material is pounded by the hammers until it is small enough to pass through the grate openings. The size of the output material in horizontal type hammermills is therefore controlled primarily by the size of the opernings in the grate.

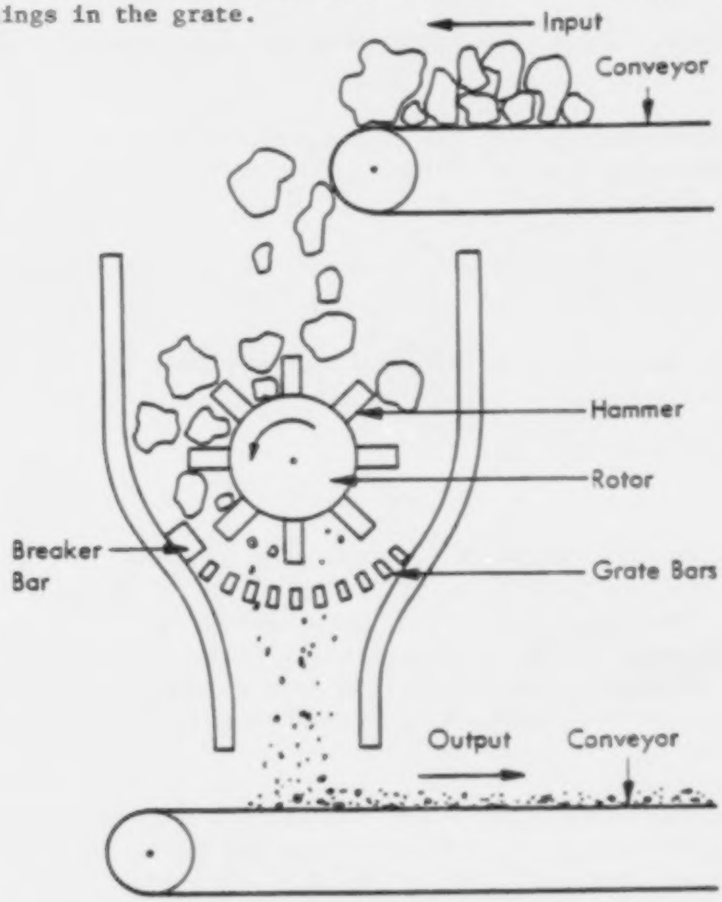


Figure 16. Horizontal shaft hammermill.

Vertical shaft hammermills, shown in Figure 17, have the rotor shaft mounted in the vertical position. The lower shaft bearing is a thrust type to support the weight of the shaft. The input material enters at the top and flows by gravity parallel to the shaft axis. The upper section of the outer housing is cone-shaped and tapers down to a throat section and into a straight cylinder section. The upper hammers start the reduction process as the material drops downward towards the throat section. Once the material passes the throat section, it is further reduced by the action of the lower hammers and the breaker bars on the inner housing walls. The final shredded product is swept horizontally out through the discharge chute at the bottom. Material entering the shredder which cannot be reduced is automatically rejected through a chute in the upper section of the machine.

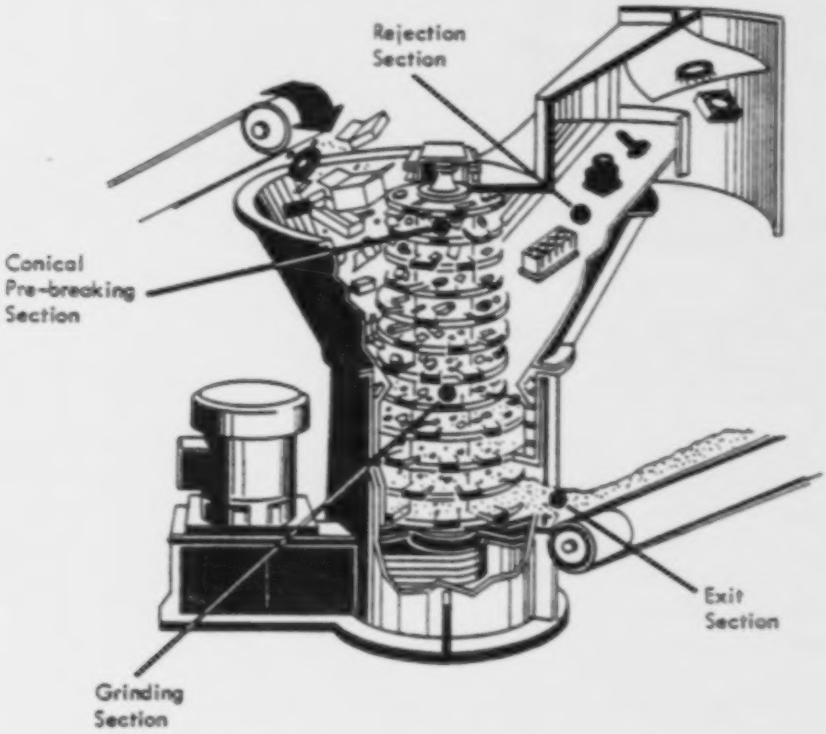


Figure 17. Vertical shaft hammermill.

Two types of grinders are being used as secondary shredders in waste-to-energy systems - roller grinders and disc-mill grinders. In both grinders the shafts are vertical. In the roller grinder, shown in Figure 18, a set of geat-like rollers are mounted around the periphery of the rotor. The inner surface of the tapered housing is ribbed. The income material is introduced into the upper part of the machine and is first exposed to a set of breaker bars which breaks up large objects. The material then enters the space between the rotor and the housing. The action of the rolling gears and the tapered outer ribs progressively reduces the size of the material as it drops down to the exit.

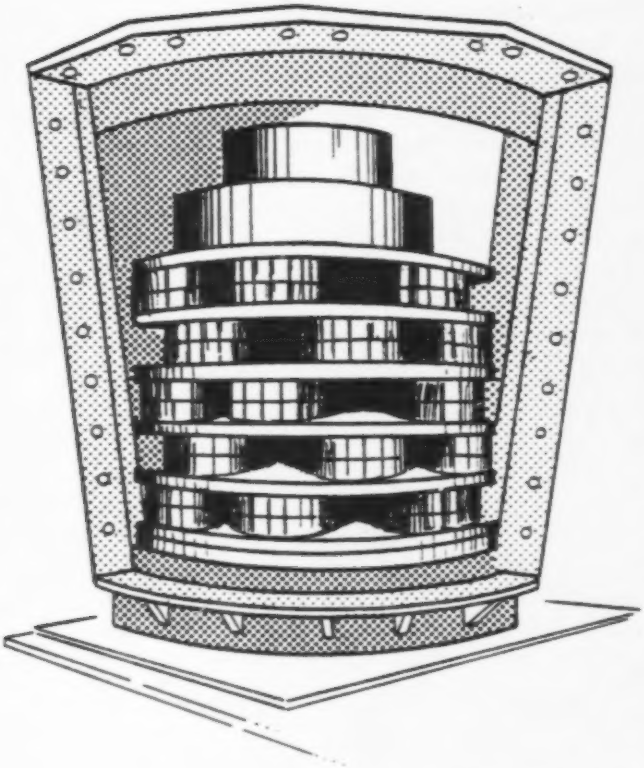


Figure 18. Cross-section of a roller grinder

The disc mill grinder, shown in Figure 19, is used to produce a very fine grind of MSW. The material is ground between two large discs--one stationary and the other rotated by the vertical shaft. Each disc has teen on its active surfaces. The income material enters through an opening in the center of the upper stationary disc, and is impelled by centrifugal force between the two discs, where it is ground and exits through an outlet at the circumfrence of the housing.

The flail mill is being used as a primary shredder in at least one waste-to-energy system. The shredding is done by multiple linked arms or chains mounted on opposed rotors. The incomeing waste is passed between the two sets of rotating flails and is thereby reduced in size. Since flail mills pass all imput materials quickly without repeated impacts, wear and energy requirements are lower than in other types of shredders. However, the degree of shreddings is usually less that other shredders.

The ball mill is being used as a secondary shredder at one waste-to-energy plant. Ball mills, as shown in Figure 20, have a cylindrical shell, rotating on a horizontal shaft, and are charged with a grinding medium such as

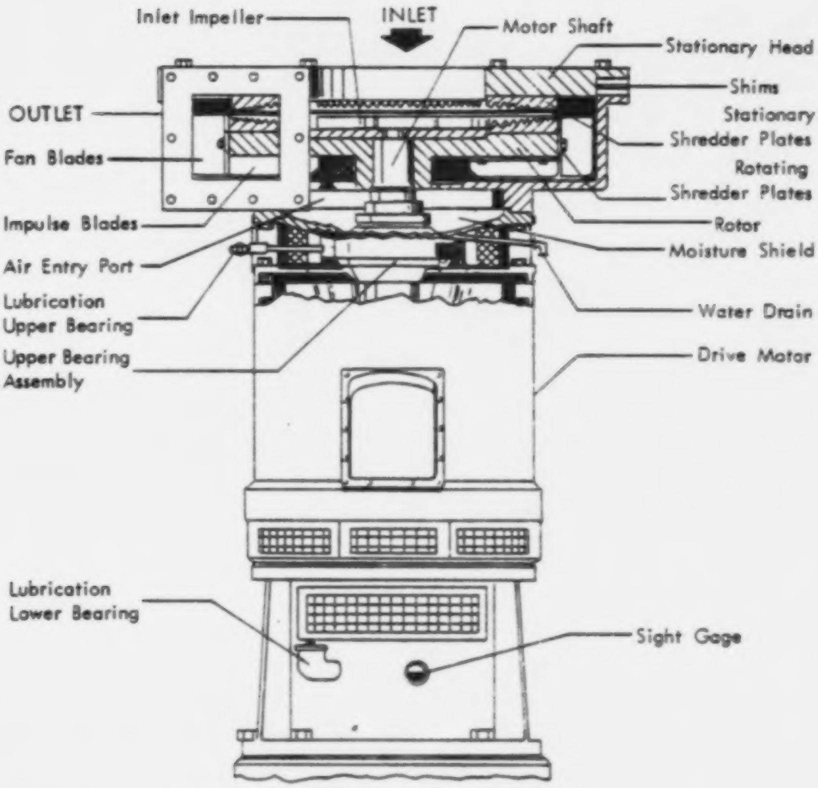

Inlet Impeller
INLET
Motor Shaft
Stationary Head
Shims
Stationary Shredder Plates
Rotating Shredder Plates
Rotor
Moisture Shield
Water Drain
Drive Motor
OUTLET
Fan Blades
Impulse Blades
Air Entry Port
Lubrication Upper Bearing
Upper Bearing Assembly
Lubrication Lower Bearing
Sight Gage

Figure 19. Disc-mill shredder.

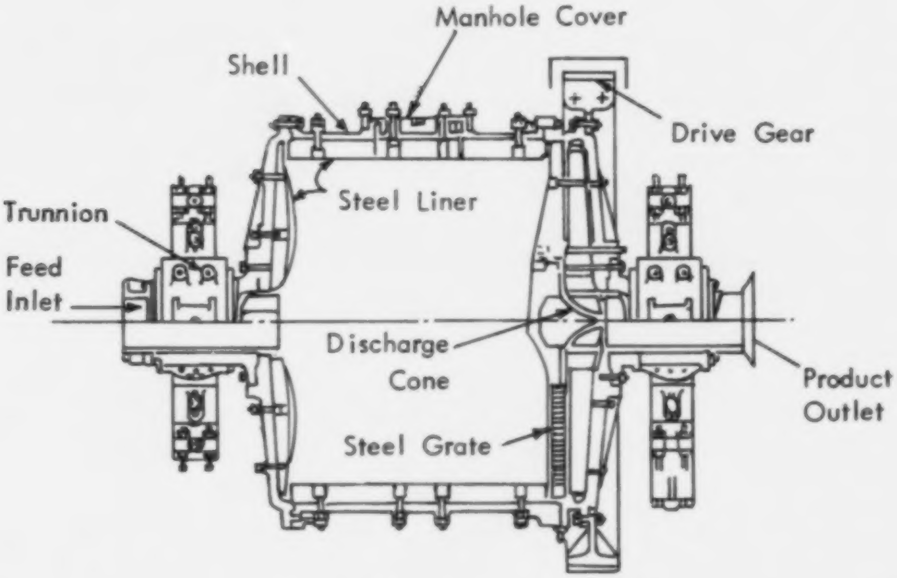
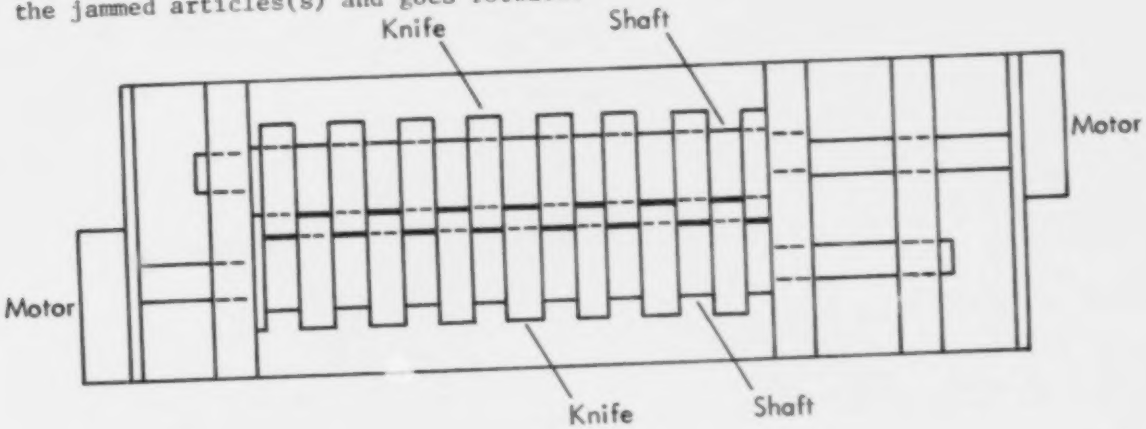

Manhole Cover
Shell
Drive Gear
Steel Liner
Trunnion
Feed Inlet
Discharge Cone
Product Outlet
Steel Grate

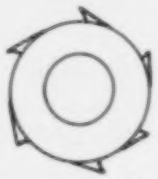
Figure 20. Ball mill.

steel balls. The size reduction is effected by tumbling of the balls on the material. Both batch and continuous ball mills are available. In batch-type mills, openings are provided through which the grinding medium and the process material can be loaded and discharged. In continuous-type mills, material is fed and discharged through hollow trunnions at opposite ends of the mill.

A recent European development is the knife-type shredder, shown in Figure 21. It has two shafts which rotate in opposite directions (towards the center of the machine). The "knives" are attached to the shafts in an alternating, complementary configuration, with little space between the knives. Each shaft is driven by a separate hydraulic motor at slow variable speeds (0 to 40 revolutions per minute). The hydraulic motors are driven by an electric motor and high pressure pump. The electric motor runs at a constant speed in a constant direction; all variations in speed and direction of the shafts are accomplished through the use of hydraulic fluids. Shredding is accomplished through the following process: (1) the MSW enters the top of the shredder, (2) it is directed to the center of the turning shafts, (3) is torn apart by the knives as they rotate in opposite directions, and (4) the shredded waste is discharged from the bottom. Other features available in this type of shredder are hydraulic rams for force feeding and an ejection system for unshreddables. The knife-type shredder has a blockage control system; where too much resistance is met, the machine automatically reverses, releases the jammed articles(s) and goes forward.



Top View



Sideview of Knife

Figure 21. Knife shredder.

Experience: A survey[183] shows that there were over 50 installations of solid waste shredders in the United States (listed in Appendix D1). They are being used to process a variety of solid wastes including municipal, industrial, commercial, oversize bulky wastes, institutional, wood, incinerator residue, paper, sewage , railroad drainage and plastics. The shredded waste is being used for landfill, incineration, energy recovery, pyrolysis, ferrous separation, baling, and composting.

All of the waste-to-energy systems presently in operation or expected to be operational by 1978 have at least one shredder in the system. The types of shredders being used in these systems are given in Table 6. Details of 11 shredders being used or planned in these systems are given in Appendix C. Although a considerable number of shredders have been installed in the last few years, there is as yet comparatively little published data on the performance of shredders on MSW.

Performance data for some shredders operating on MSW have been reported by Trezek el al,[193] Ruf,[163] Reinhardt et al.,[151] Shannon et at.,[171] and analyzed by Anath et al.[13]

Trezek's study [193] was conducted with a comparatively small (9.1 metric tons per hour) horizontal hammermill, under controlled laboratory conditions. The effects of moisture content, feed rate and rotor speeds on size distribution and energy consumption were investigated. The data show that increasing the moisture content and decreasing the speed produces a coarser product. The energy consumption was found to be a parabolic function of the moisture content and feed rate.

Ruf[163] reported shredding data collected at Gainesville, Florida, experimental composting plant. The main objective of the project was to determine maintenance requirements, equipment reliability and costs. Data were collected on a primary shredder (horizontal-shaft hammermill, with a capacity of 27.3 metric tons per hour) and a secondary shredder (horizontal hammermill with a capacity of 18.2 metric tons per hour). Bulky material was removed prior to primary grinding, and ferrour metal was removed after the first shredder, prior to secondary grinding. The principle operating problem reported was plugging of the shredders, due to material jamming between the rotor and the housing, causing the machine to brake to a halt. Problems with dust, flying objects and noise were also encountered. The dust contained a considerable number of broad grouping of microorganisms, and the atmosphere in the vicinity of the shredder was found to be a potential hazard to the health of exposed personnel. Capital and operating costs were reported but not considered to be representative because the plant was operated only a portion of the day, administrative and supervisory costs were not included, and many modifications were made during the data collection period.

TABLE 6. SHREDDER TYPES USED IN WASTE-TO-ENERGY SYSTEMS

System	Shredder Type
Ames, Iowa	Horizontal hammermill (P,S)
Baltimore, Maryland	Horizontal hammermill (P)
Baltimore County, Maryland	Horizontal hammermill (P)
Charleston, West Virginia	Vertical hammermill (P)
Chicago, Illinois	Horizontal hammermill (P)
	Roller mill (S)
East Bridgewater, Massachusetts	Flail mill (S)
	Ball mill (S)
El Cajon, California	Horizontal hammermill (P)
	Disc mill (S)
Milwaukee, Wisconsin	Horizontal hammermill (P)
	Vertical (S)
Palmer Township, Pennsylvania	Unknown (P)
	Unknown (S)
Pompano Beach, Florida	Vertical hammermill (P)
	Horizontal hammermill (S)
Riverside, California	Unknown (P)
St. Louis, Missouri	Horizontal hammermill (P)
Southgate, California	Horizontal hammermill (P)
Washington, D.C.	Horizontal hammermill (P)
	Vertical hammermill (S)

P = Primary shredder.
S = Secondary shredder.

Reinhardt and Ham[151] reported on their study of shredded MSW at Madison, Wisconsin, which was initiated in 1966. Two shredders, a 10 metric tons per hour horizontal shaft hammermill and a 13.6 metric tons per hour vertical shaft hammermill, were evaluated under similar conditions. The study showed that the energy consumption per ton of waste processed was less for the vertical shaft hammermill than for the horizontal-shaft hammermill. Some operational problems were encountered with the vertical shaft unit, including internal jamming, explosions, and trouble with the radial and thrust bearings on the main shaft.

Hammer wear is the major maintenance problem in the shredding of MSW. As the hammers wear, their effectiveness in shredding the waste decreases, due to blunting the hammer tips and increased clearence between hammers and the housing and/or grates. When the hammers become worn they must be retipped. After a number of retippings the entire hammer must be replaced. Some manufactureres of hammermills offer reversible-action hammer rotors, so that both sides of the hammers can be utilized before retipping, which increases the amount of waste that can be processed before shutdown for repair of the hammers.

Savage and Trezek[164] measured hammer and grate bar wear in a horizontal hammermill. Both hard-faced and nonhard-faced hammers were used in the study. Also, hard-surface welding material and base hammer material were analyzed for their resistance to wear. It was found that (1) impact plays an insignificant role compared to abrasive forces; (2) the incoming waste should be fed uniformly across the rotor width to avoid localized hammer wear; (3) hard-faced hammers wear less than nonhard-faced hammers; and (4) a reduction in hammer wear occurred at reduced rotor speed.

There is comparatively little definitive data on the wear of the shredders in full-scale commercial plants. Furthermore, standard procedures for measuring and evaluating wear are not being used in the industry. Each plant operator decides on the schedule to be followed in retipping worn hammers. Some operators retip the hammers every day, others every week, and some do not retip at all, but simply change the hammers when they become badly worn. The optimum procedures for retipping hammers based on performance and economics have not been established.

Magnetic Separators

Function: Magnetic separators are used to remove magnetic material, primarily ferrous metals, from the mixed municipal solid waste. There are two important reasons for removing the ferrous metals in waste-to-energy systems; (1) to increase the heat content of the refuse derived fuel or feedstorck; and (2) to recover a saleable product. There is approximately 8 percent ferfous metal in the incoming MSW (Smith, 1976),[178] so that its removal increases the heating value of the recovered fuel or feedstock about 900 kilojoules per kilogram. Futhermore, the removal of the metal reduces wear on subsequent processing and handling equipment and also reduces the amount of ash when the fuel is burned.

There are presently four markets for ferrous metal recovered from MSW: steel manufacture, detinning, copper mining, and ferroalloy production. A list of solid waste processing facilities which recover or plan to recover ferrous metals from MSW is given in Appendix D-2.

In all the waste-to-energy systems expected to be operational by 1978, the MSW is shredded prior to magnetic separation. In most systems the magnetic separator is located after the primary shredder. In some cases an air classifier is used to remove the efrrous metals from the shredded MSW along with other heavy materials and a magnetic separator is used to separate the ferrous metals from the heavy fraction.

Description: There are two basic types of magnetic separators used for MSW--the belt-type and the drum-type.

The principle of a simple belt-type magnetic separator is shown in Figure 22. The separator is usually positioned over the discharge end of the MSW feed belt, as shown, The attraction of the magnet lifts the ferrous metal out of the MSW, and the belt on the magnetic separator conveys the metal along the magnet until it reaches the end of the magnetic field and drops into a receiving bin. A more complex belt-type magnetic separator, devloped specifically for MSW is shown in Figure 23. This design was developed to overcome the problems of entrapment of pieces of paper and plastic along with the ferrous metal. This new design consists of three separate magnets arranged in a "V" shape, and hence referred to as the "hockey stick" design. A rubber belt conveys the material from one magnet to the next; the first magnet picks up the material from the mixed MSW. The material picked up by the first magnet is conveyed around the bend of the "V" to the second magnet. The polarity of the second magnet is reversed from the first magnet. Passage around the bend and the reversal of polarity between magnets agitates the adhering material and tends to release trapped nonmagnetics. After passing over the second magnet, the material is momentarily released as it passes over an air-gap between the second and third magnets. When an attrachted tin can or other magnetic material reaches the air gat it falls away, releasing the can and belt. The forward motion of the can carries it into the field of the last magnet, and it is pulled back up to the blet and conveyed to the discharge area. The released nonmagnetic material is not affected by the last magnetic field and falls away.

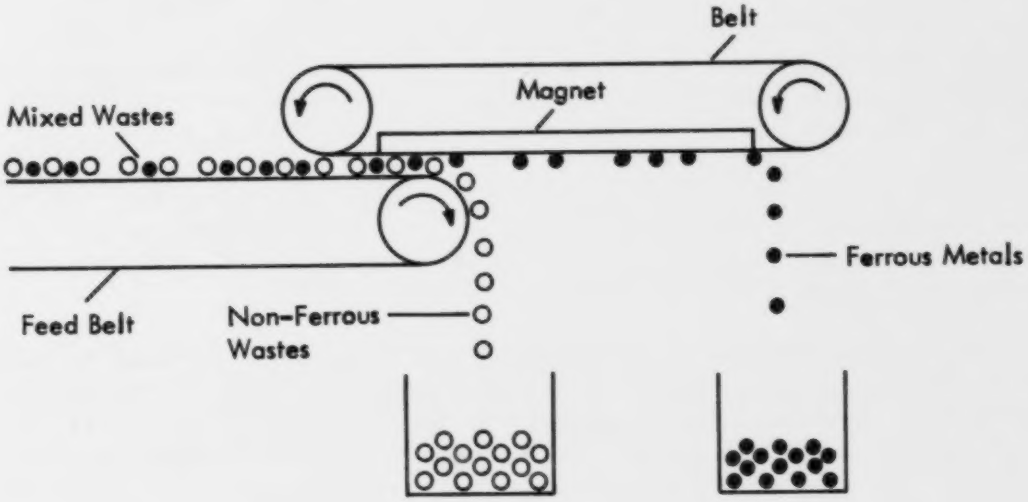


Figure 22. Principle of magnetic separation (belt type).

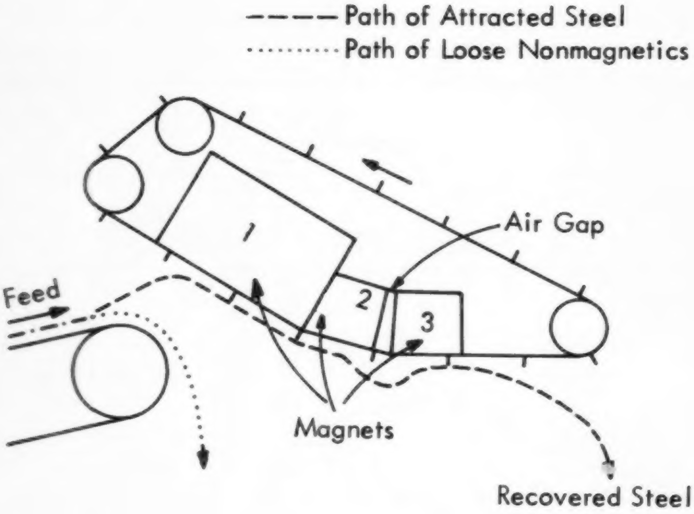


Figure 23. Principle of "hockey stick" belt magnet.

The principle of a single drum-type magnetic separator is shown in Figure 24. The drum is preferable positioned over the head pulley of the belt carrying the mixed MSW. A stationary magnet is located inside the revolving drum shell. The ferrous metal in the MSW is picked up by the magnet and is conveyed around the drum circumfrence until it passes the magnetic field and is discharged. The single drum magnet tends to entrap peices of paper and plastics, just as the simple belt magnet does. To minimize this problem, two drum magnets, with an intermediate belt conveyor are recommended as shown in Figure 25. The first drum is suspended above the end of the MSW feed conveyor and rotates in the direction of the material flow. The ferrous material is picked up and tossed forward to the intermediate belt conveyor. Most of the nonmagnetic materials falls to a take-away conveyor located below the first drum. The second drum, which can be smaller than the first because of less material flow, is positioned over the discharge end of the intermediate conveyor, and rotates in a direction opposite to the material flow to avoid bridging or jamming. The ferrous metal is carried over the top of the drum and released on a conveyor or bin on the far side.

Experience: There is as yet relatively little recorded experience with magnetic separators operating on MSW. A prominent manufacturer of magnetic separators lists 24 solid waste magnet installations, with the earliest installed in 1973. The five waste-to-energy systems, listed in Table 7, use magnetic separators which affect the energy product. One of the first magnetic separators used in a waste-to-energy system was the St. Louis demonstration plant in 1972 (Parkhurst, 1976). The belt magnet unit was initially located after the shredder. However, after an air classifier was added to the system, the magnetic separator was relocated to the heavy fraction stream from the air classifier. Therefore, in this system, the amount of magnetic metal (and other nonburnables) in the RDF was not affected by the magnetic separator but by the air classifier.

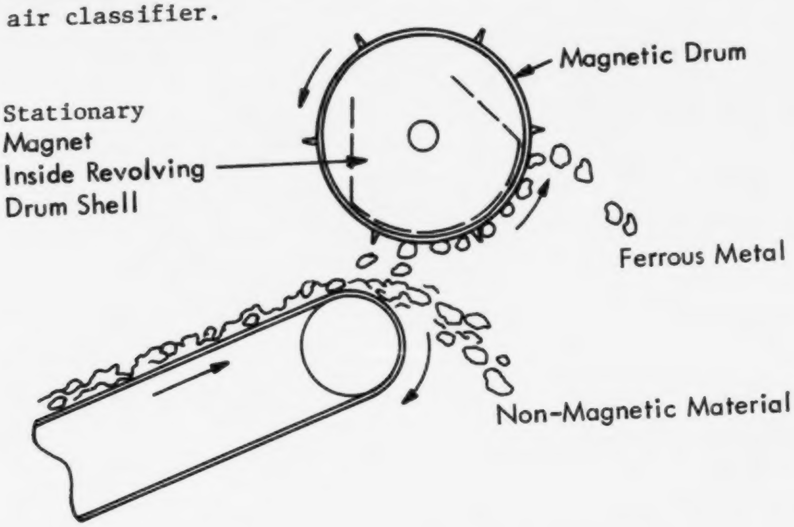

Magnetic Drum
Stationary
Magnet
Inside Revolving
Drum Shell
Ferrous Metal
Non-Magnetic Material

Figure 24. Principle of single drum magnetic separator.

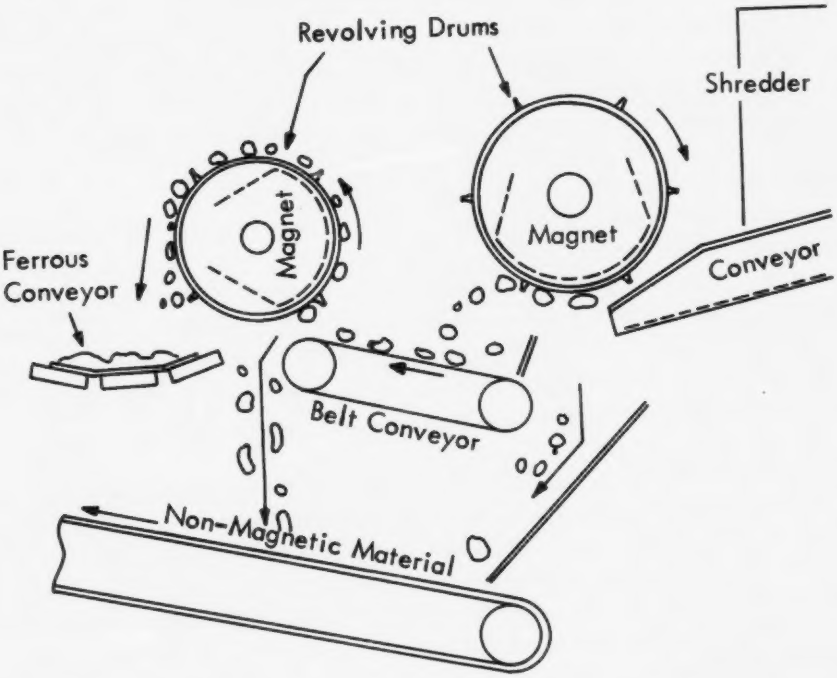

Revolving Drums
Shredder
Magnet
Magnet
Ferrous
Conveyor
Conveyor
Belt Conveyor
Non-Magnetic Material

Figure 25. Principle of dual-drum magnetic separator,

TABLE 7. MAGNETIC SEPARATOR TYPES USED AT WASTE-TO-ENERGY SYSTEMS[a]

System	Magnet Type
Ames, Iowa	Belt
Baltimore County, Maryland	Belt
Charleston, West Virginia	Drum
East Bridgewater, Massachusetts	Belt
El Cajon, California	Drum

[a] List includes only those systems in which the magnetic separator affects the energy product stream.

Data on magnetic separators at the Ames plant show that the amount of ferrous metal recovered during a 3-month period was 5.4, 5.9, and 6.6 percent, respectively.[60] However, the efficienty of the recovery based on the amount of ferrous metal in the raw MSW, and the purity of the recoverd metal fractions were not reported.

The separation of magnetic metals has been performed at the East Bridgewater plant, using a magnetic pulley and a suspended belt magnetic separator. The only available information on the performance is that the recovery rate is 6.8 percent and "this separator produces a magnetic fraction that is adequately cleaned for the current market".[19]

Although magnetic separators have been used for numerous industrial applications, their use on MSW presents some unusual problems. The amount of ferrous metals in MSW is relatively high as compared with tramp metal removal requirements from other industrial products. There is a tendency for nonmagnetic materials, such as paper and plastic, to be entrapped with the ferrous metal, thereby reducing the purity of the recovered metal product. Furthermore, the sharp edges on the ferrous metal tend to make the life of rubber belts very short. Few people in the solid waste industry have expert knowledge about magnetic separation equipment. Even fewer are knowledgeable about magnetic theory as it applies to the separation of shredded MSW.

Until recently the designers of MSW processing plants had to use conventional magnets, which were designed for unrelated industries. These magnets were in the form of magnetic pulleys, magnetic drums or suspended box magnets. They did not work well on shredded MSW because of the above unique conditions. A design was needed for extraction and cleaning of a continuous flow of fast moving steel buried in a comparatively deep burden of nonhomogenous material. The challenge was approached in several ways by magnet designers. The two principal designs recently developed specifically for MSW are the dual drum design and the "hockey stick" belt magnets, described earlier. There is as yet insufficient experience with either of these new magnets to properly evaluate their performance and economics on shredded MSW. Preliminary data indicate that they perform better than the early designs, but more data are required before definitive conclustions can be drawn.

Air Classifiers

Function--Air classifiers are used in waste-to-energy processing lines to segregate the MSW stream into two fractions. One fraction consists of light materials (paper, plastic, wood, dust, etc.); the other fraction is composed of heavy materials (metals, glass, etc.). Air classification concentrates the combustibles into the light fraction as a fuel product. Also, the metals and glass can be separated from the heavy fraction and sold in secondary markets. Generally, the air classifier is placed after the magnetic separator and before the secondary shredder.

Description--Air classifiers separate MSW relative to the particle size and density. All of the classifiers use one of two types of air transport to aid in the separation. A positive pressure air transport system has the effect of pushing the MSW through the system. This is accomplished by attaching a blower to the system and creating a higher pressure within the system relative to the external environemtn. The other method, a negative-pressure air transport system, pulls the MSW. An exhaust fan is placed at the end of the system,creating a lower pressure within the system (the same effect as a vacuum).[65]

There are five types of air classifiers: straight, zigzag, vibrating, rotary drum and concentric tube.

MSW enters the straight air classifier, illustrated in Figure 26, at the mid-section of a long, thin, vertical chamber. An airlock is used for feeding, to aid in maintaining a controlled, metered flow of MSW, and prevents any change in internal pressure which would adversely effect the performance of the airflow. This type of air classifier uses an upward (negative) airflow through the vertical chamger to effect separation. The separation occurs because the light fraction follows the airflow upward and the heavy fraction falls to the bottom.

MSW is fed into zig-zag classifiers, shown in Figure 27, at the mid-section of the housing. There are step-like structures above and below the inlet within the housing. These classifiers use gravitational force and the impact upon the sides of the classifier to minimize entrapped "lights." The separation is effectec by an upward negative airflow. The shape of the structure creates a swirling-air effect which enhances the separation. "Lights" follow the airstream up and "heavies" fall.

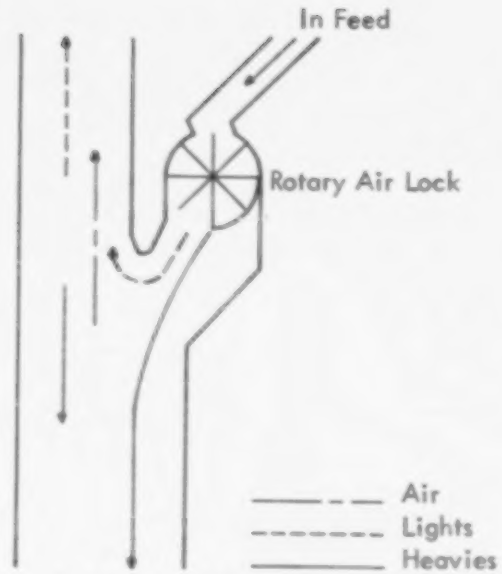

In Feed
Rotary Air Lock
Air
Lights
Heavies

Figure 26. Principle of straight air classifier.

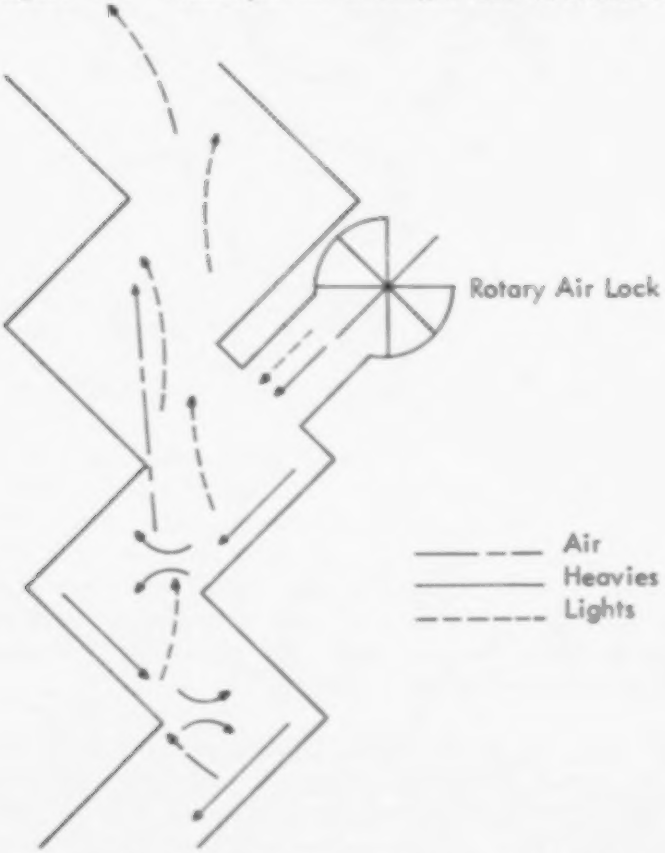

Rotary Air Lock
Air
Heavies
Lights

Figure 27. Principle of zigzag air classifier.

Vibrating air classifiers, illustrated in Figure 28, combine the gravitational, stratifying effect of vibration and the density classification introduced by an airflow. The MSW is fed into the classifying chamber where it remains in contact with a gradula sloping surface which vibrates along a 20-40 degree axis. Air comes through the inlet, "heavy" discharge chute, and the fluidizing air grids. The light infraction, moved to the top by vibration, is carried by the airstream around the U-shaped curve and discharged upwards while the heavy fraction is discharged at the bottom.[80]

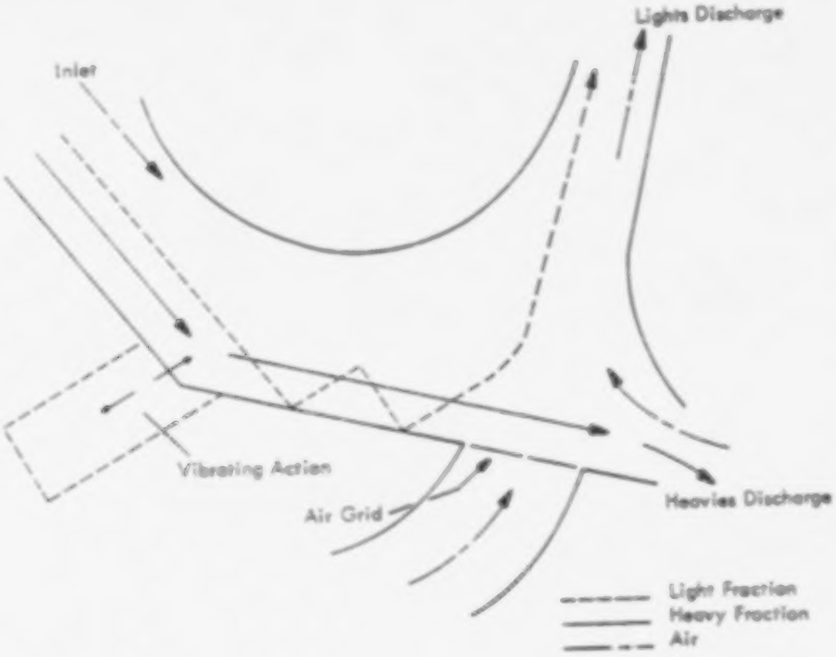


Figure 28. Principle of vibrating air classifier.

The rotary air classifier, shown in Figure 29, has a drum which is installed at an angle. The MSW is fed into the lower end of the drum by a conveyor. The drum rotates, allowing entrapped light particles to separate from the heavy fraction. A negative airflow is used to pull the light fraction the length of the drum; the heavy fraction falls to the lower end of the drum and out a discharge chute. The light fraction enters a plenum where the air velocity decreases and the light fraction drops. Dust follows the reduded airflow up the plenum.[69]

In the concentric-tube air classifier, shown in Figure 30, the MSW enters at the top of the inner cylinder and hits a cone-shaped object used to agitate and loosen the waste. The MSW then enters the outside cylinder where there is an upward airflow. The light fraction follows the airstream, upward and the heavy fraction drops.

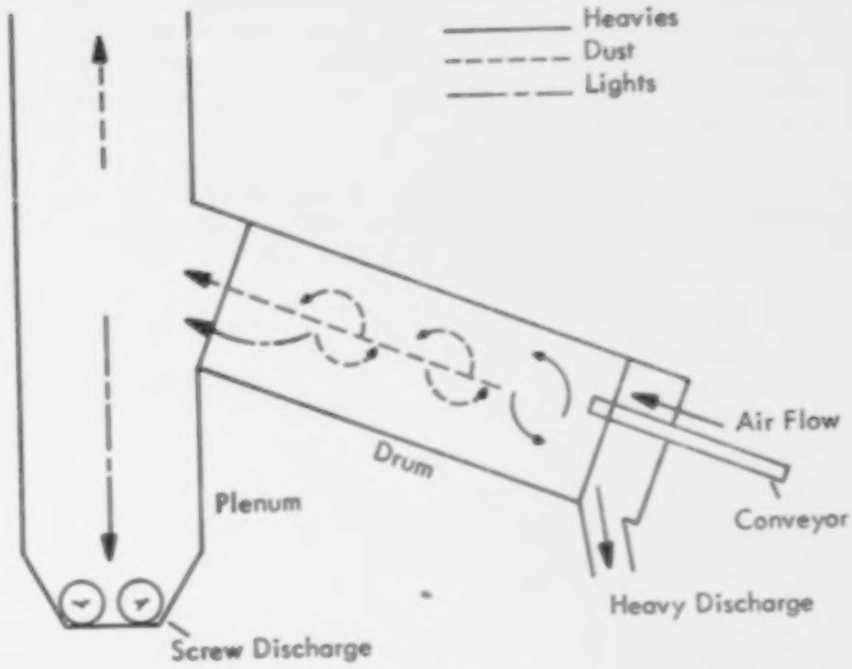

Heavies
Dust
Lights
Air Flow
Drum
Conveyor
Plenum
Heavy Discharge
Screw Discharge

Figure 29. Principle of rotary air classifier.

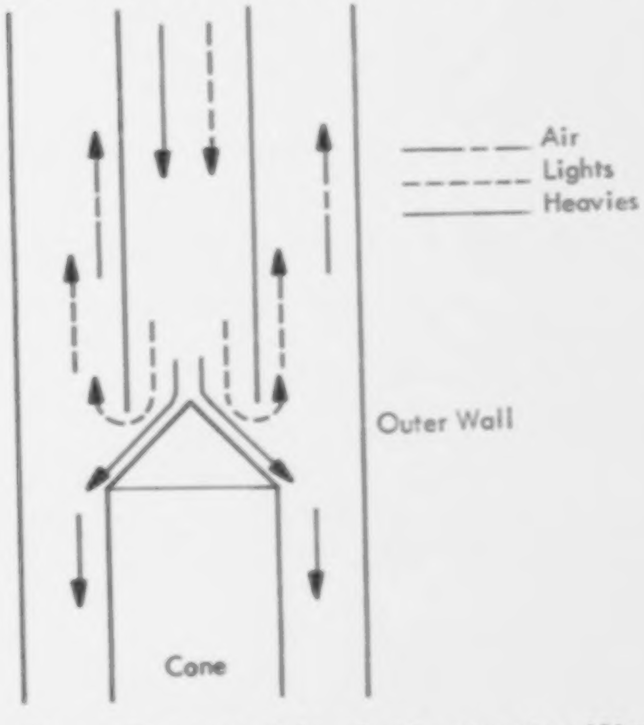

Air
Lights
Heavies
Outer Wall
Cone

Figure 30. Principle of tube air classifier.

Air classification systems usually include some type of feeder, a fan (with motor) and a cyclone separator, which is used to segregate the light fraction from the airstream. Most systems use a negative airflow and rotary airlocks (with motors), and some systems also use air filtering equipment for dust collection.

Experience: Table 8 lists the types of air classifiers used in present waste processing systems. Tests have been run on the straight air classifier at St. Louis, with the findings as follows:[54]

1. Over a period of 1 year an average of 80.6 percent of the raw refuse was separated into the light fraction.

2. The composition of the raw MSW and the light fraction was as follows:

	Raw MSW (Percent by wt)	Light Fraction (Percent by wt)	Percent of Initial Raw MSW
Paper	54.1	62.8	93.6
Plastic	4.5	7.8	86.0
Wood	3.2	2.7	67.9
Glass	4.2	2.9	55.7
Magnetic Metals	6.2	0.2	2.6
Other Metals	0.6	0.39	52.3
Organics	5.8	0.8	52.8
Miscellaneous	21.4	22.4	84.4

3. The results of five particulate emission tests showed an average of 0.74 kilograms per megagram.

4. There were significant bacteria and virus counts in the emissions.

At Ames, the moisture content of the MSW has had a negative effect on the classifier's performance. To counteract this, the airflow was adjusted accordingly. Also, MSW entering the separation chamber was being thrown horizontally with more force than originally intended. This was corrected by installing a baffle to divert the material downward.

TABLE 8. AIR CLASSIFIER TYPES USED IN WASTE PROCESSING SYSTEMS

System Location	Type of Air Classifier
Ames, Iowa	Straight
Baltimore County, Maryland	Concentric Tubes
Chicago, Illinois	Vibrating
El Cajon, California	Zigzag
Milwaukee, Wisconsin	Zigzag
Pompano Beach, Florida	Vibrating
St. Louis, Missouri	Straight
Washington, D.C.	Vibrating
Houston, Texas	Rotary
New Orleans, Louisiana	Vibrating

A vibrating air classifier has been installed and tested at Washington, D.C., and vibrating air classifiers were installed at Chicago, Illinois, Pompano Beach Florida, and New Orleans, Louisiana. The tests at Washington, D.C. had several procedural inadequacies and were therefore not published. Manufacturers of this type of classifier claim the following:[80]

1. There is less entrapment.

2. Airflow need is less.

3. Retention time of particles in the separator is greater.

4. There is less sensitivity to particle size, and separation is more dependent on specific gravity.

Zigzag air classifiers have been tested in the laboratory at limited scale by several firms. Stanford Research Institute conducted tests to determine the usefulness of air classifiers in the solid waste field.[21] The tests using MSW were not useful for the purposes of this discussion because the emphasis was on the separation of individual components (e.g., paper, plastic, or metals) rather than on the effect of the process on the fuel fraction.

The El Cajon, California, and Milwaukee, Wisconsin, systems have zigzag classifiers. At El Cajon, some problems have been experienced. The problems involve the relationship of the airflow and classifier shape, which can cause vortex currents. If the airflow is too great, the vortex effect will be too great and separation will be impeded. The same result occurs if the airflow is insufficient. Steps were taken to select the proper airflow relative to the configuration of the classifier. No data are available at this time from El Cajon or Milwaukee.

A concentric-tube type air classifier is being used at Baltimore County, Maryland. There is a proprietary mechanism in this classifier which breaks up chunks of MSW to improve the separation efficiency. This installation has encountered problems due to back pressure from the cyclone.

A rotary drum air classifier was installed in Houston, Texas, and tests have been conducted on a pilot unit. The tests encompassed effects of feed rate, drum incline, air velocity, revolutions per minute of drum, and MSW characteristics.[69]

The manufacturers of rotary drum classifiers claim:

1. The classifier works best on MSW with a shred size of 10 to 30.5 centimeters.

2. Better separation is obtained with lower air velocities.

3. MSW remains in the separation zone for a longer period of time.

4. Rotating action eliminates entrapment.

5. There is less efficiency reduction due to feed surges.

6. When finer (than 10 to 30.5 centimeters) fuel stock is necessary, secondary shredders will have to be installed after the air classifiers.

Generally, there are several performance questions which are common to all air classifiers and which have not been adequately tested and reported to date:

- Optimum airflow and air velocity.
- Methods to eliminate unburnables from light fraction.
- Methods to eliminate entrapment of lights with heavies.
- Full scale performance data.

Screens

Function: Screens are used to allow a system operator to extract material within a particular size range from the MSW stream. Screens represent a type of separation equipment, segregating the MSW by particle size only instead of by density and particle size as the air classifier does. The position of a screen in the process line varies tremendously; it could be the first piece of equipment or be installed after the shredders or air classifier. For example, a screen may be used to eliminate comparatively large particles (glass, metals, etc.), before size reduction takes place, or it may be used to remove fine material after primary and/or secondary shredding.

Description: There are three types of screens that may be used in MSW-to-energy systems: Vibrating, rotary, and disc.

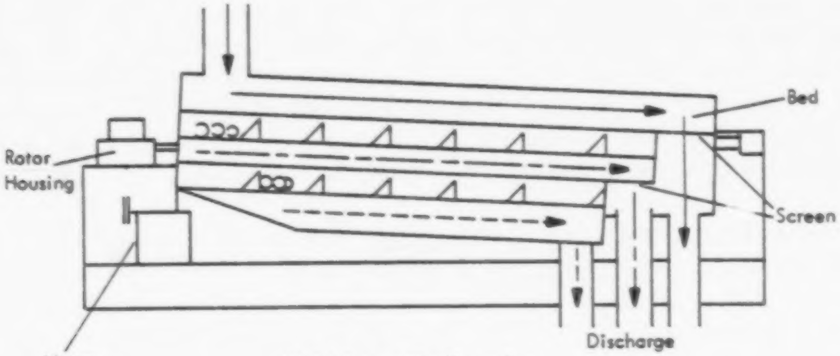
Vibrating screens are divided into gyrating and reciprocating. The separation accomplished through the use of screens is based on particle size. The screens are equiped with openings of a certain size which allow particles smaller than the opening to pass through. The motion serves three purposes: (1) it allows more particles to come in contact with the screen surface; (2) it minimizes entrapment of small particles; and (3) it aids in moving the solid waste down the screen. The screens are generally set at an angle so gravity can also assist in moving the MSW the length of the screen.[187]

Gyrating screens, illustrated in figure 31, are equipped with a motor at one end of the screen housing. The opposite end can pivot but does not add any additional motion. The rotor has counterbalancing weights which create an easy horizontal side-to-side motion.[187]

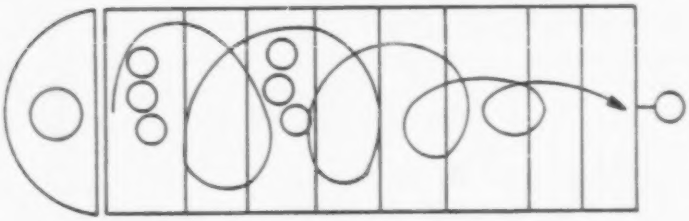
Reciprocating screens can be vibrated two ways. In all cases the motion is caused by a rotor, counterweight system. (1) The action can be along an angle of 20 degrees to 45 degrees, as shown in Figure 32a. This type of motion causes the entire housing, which is suspended on springs, to move along the angle, and the particles leave the screen surface. Then the particles land, and the housing returns to the original position, thereby moving the particles forward. (2) The action is a rocking motion, end-to-end, in which the screen is on an incline and the housing is on springs. As illustrated in Figure 32b, the housing deps at one end while rising at the other in an alternate fashion, creating the rocking action. Both of these actions occur under much higher speeds that gyrating screens. Generally, the screen surfaces in all vibrating screeners are made of nylon or wire mesh.

The rotary (trommel) screen, illustrated in Figure 33, looks like a long metal cylinder with holes punched in it. There is a motor at one end which rotates the drum. The length and diameter of the drum have a direct relationship to the efficiency of the trommel. The longer the drum, the longer the

MSW will remain in contact with the screen. And, the greater the diameter, the more effective the trommel will be in breaking up large objects, such as trash bags. Also, the rate of rotation plays a role in the trommel's separation efficiency.



Multi-Screen Configuration

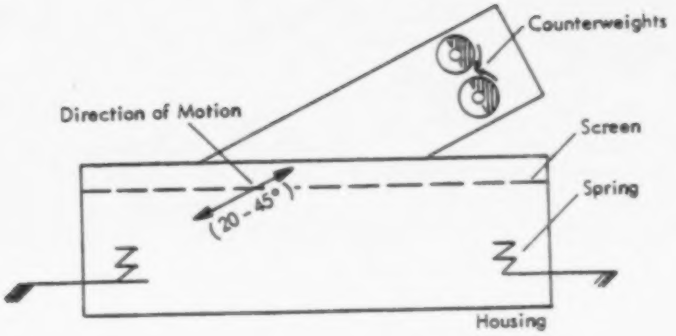


Action of Material on Screen Surface

Bouncing Ball Screen Cleaner

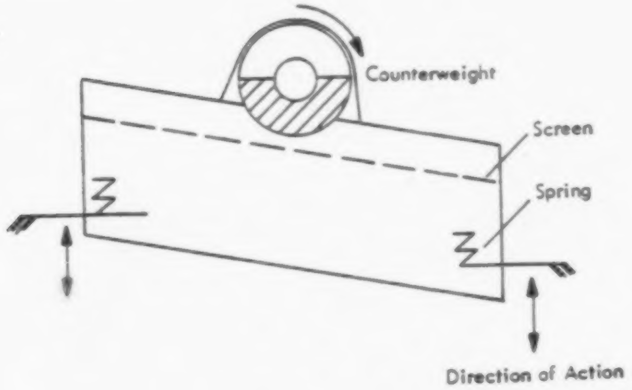
Figure 31. Gyrating screen.

A disc screen, as illustrated in Figure 34, has a series of discs attached to small-diameter cylinders in parallel configuration. The discs from each alternating cyliner complement each other, and as the cylinders rotate, objects of small size pass through the length of the screen.


Counterweights
Direction of Motion
Screen
Spring
(20 - 45°)
Housing

Side View – Horizontal Vibrating Type

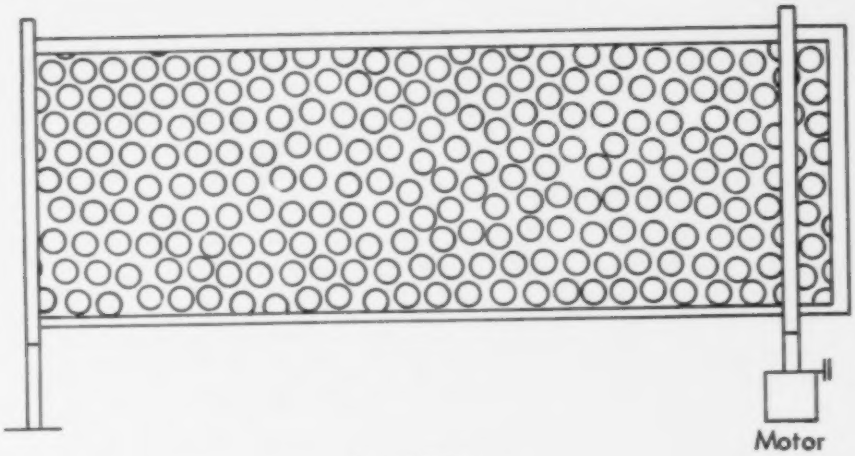
(a)


Counterweight
Screen
Spring
Direction of Action

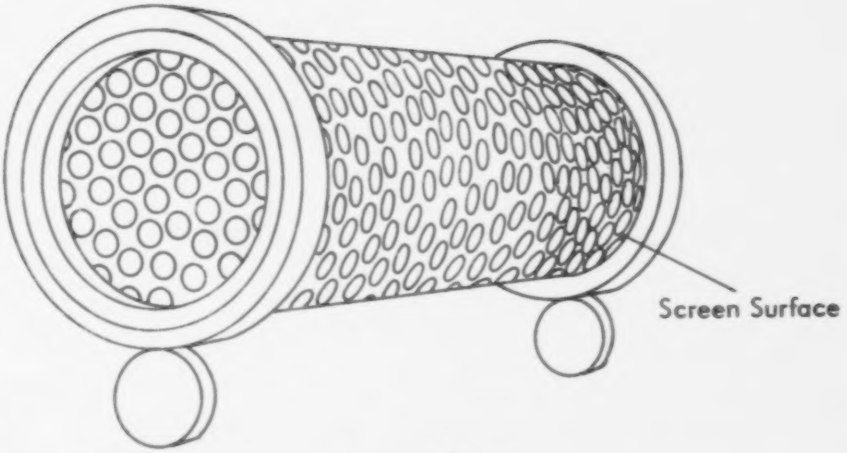
End View – Rocking Type

(b)

Figure 32. Reciprocating vibrating screens.



Side View


Screen Surface

End View

Figure 33. Rotary (trommel) screen.

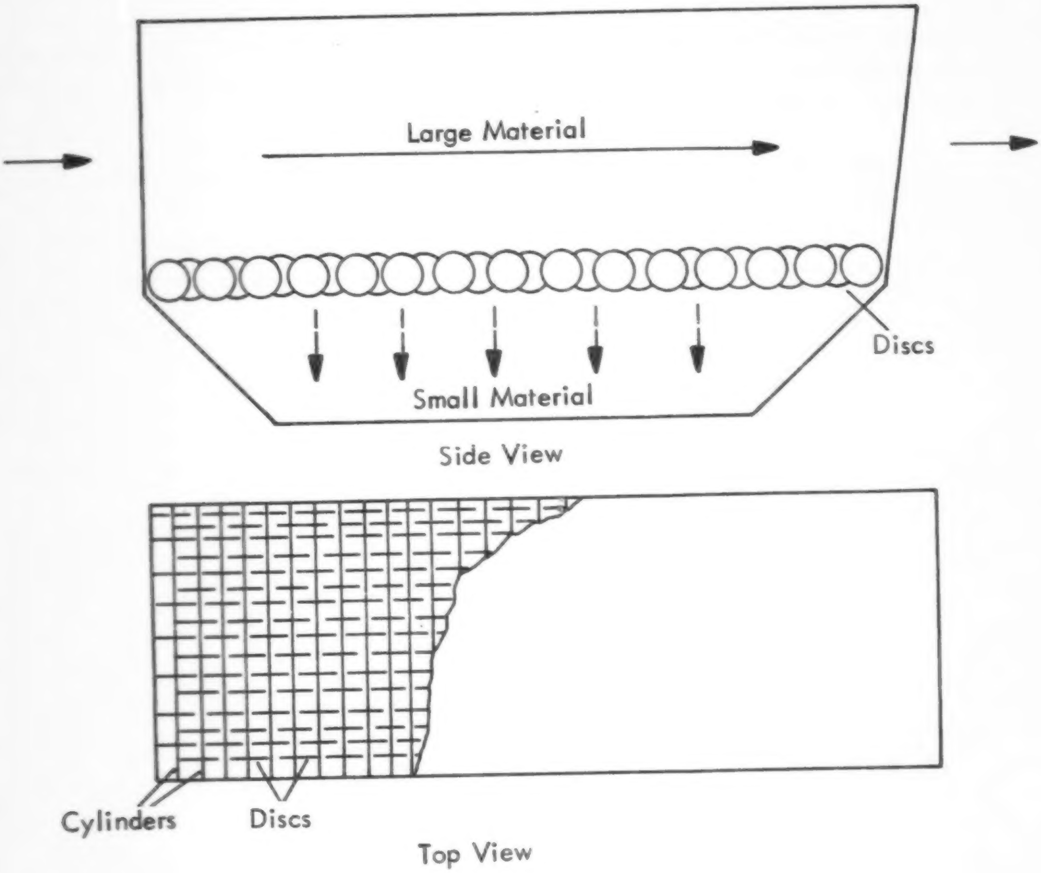

Large Material
Discs
Small Material
Side View
Cylinders
Discs
Top View

Figure 34. Disc screen.

Experience: Table 9 lists the types of screens used at various waste processing plants. Vibrating screens have previously been used extensively in the food processing industry. Their application in MSW processing is for fine screening, with screen openings as small as 0.0035 centimeters. This variety of screen can have several layers of screen surfaces to separate the MSW into several particle size groupings. However, the reciprocating motion is very jerky and the MSW actually leaves the screen surface, which could create housekeeping problems and less efficient separation. The screen wear is significant, and there is a large amount of associated vibration affecting the structure and other connected equipment.[187]

TABLE 9. TYPES OF SCREENS AT WASTE PROCESSING PLANTS

Location	Type of Screen
East Bridgewater, Massachusetts	Trommel and gyrating
El Cajon, California	Gyrating
Washington, D.C.	Trommel
Houston, Texas	Trommel
New Orleans, Louisiana	Trommel
Toronto, Canada	Trommel
Pompano Beach, Florida	Trommel
Ames, Iowa	Trommel
El Cajon, California	Trommel
Palmer Township, Pensylvannia	Trommel

In gyrating motion screens, the material never leaves the surface of the screen, so that the retention time is longer and separation is improved. As the material travels down the gyrating screen its path changes, thereby increasing particle agitation and improving separation efficiency. The bed in this type of screen is thin, increasing the chances of the particle passing through the screen.[187]

Gyrating screens often come equipped with bouncing balls to prevent blockage of the screen. Manufacturers have made laboratory tests with this type of screen using MSW, but the results have not been made available. A gyrating screen is installed at El Cajon, California, and at East Bridgewater Massachusetts. However, to date there has been no performance data from these installations.

Rotary (trommel) screens have been used in the mineral industry for many years for coarse screening. Trommels have been installed or planned at East Bridgewater, Massachusetts; Palmer Township, Pennsylvania; Pompano Beach, Florida; and New Orleans, Louisiana. Several installations also use trommels in their nonferrous metals recovery systems (e.g., Ames, Iowa and El Cajon).

NCRR, TVA, Continental Can, Vista Chemical Company, and Warren Springs Lab (in England) have been investigating the use of trommels as a first separation operation prior to shredding (called pretrommeling). NCRR, in its tests on the trommel screen[212] used a 2.7 metric diameter, 3 meter long trommel with adjustable slope of 0 to 7 degrees, 10.2 centimeter square openings in wire cloth (75 percent of surface is open) and 10 lifters (implements along the inside of the trommel which increase the retention time). They report the following findings:

1. An increase to 14 lifters increase capacity significantly.

2. From 12 trials of materials passing through the trommel, the mean was:

    a. 64 percent of magnetic metals in MSW pass through trommel.

    b. 75 percent aluminum metals in MSW pass through trommel.

    c. 96.6 percent glass in MSW pass through trommel.

3. The necessary retention time is 25 to 30 seconds.

4. The capacity was 13.6 megagrams per hour.

5. Blinding was not a problem, but cloth was caught by the wire screening.

6. Nearly all garbage bags were opened.

7. A 55 to 64 megagrams per hour unit should:

    a. Be 12.2 meters long

b. Use punch plate instead of wire screen

c. Have 12.1 centimeter diameter holes, and

d. Use a 3.2 meter diameter drum.

8. Cost savings for a system using pretrommeling are estimated to be 8.5 percent.

Some feel pretrommeling is desireable because the recoverables are in a better form for marketing, the wear on downstream equipment should be less, and energy consumption should be decreased. More testing and data are needed to substantiate the claims.

Disc screens have been used in the forest products industry to separate ice chunks from wood chips. Tests have been conducted for the separation of glass, having a nominal size of 15.2 centimeters and less, from shredded waste. Results were favorable although actual data were not disclosed. Shredded oversized bulky waste was also tested (including mattresses) and no disruption of operations occurred. The manufacturers suggest that disc screens by used after primary shredding and before secondary shredding. To date, this type of screen is not known to have been installed at any MSW processing plant.

Dryers

Function: In waste-to-energy systems, dryers are primarily used to reudce the moisture content of the MSW, thereby increasing its Btu value. Moisture reduction alos results in imporved storability, possibly imporved air classification, and possibly reduction of bacteria and virus. Generally, the dryer is installed just before or just after the air classifier.

Description--There are two types of dryers used in waste-to-energy systems: rotary dryers and fluid-bed dryers.

A rotary drying system, shown in Figure 35, includes (1) a blower to circulate the heat, and effect the MSW evacuation, (2) a combustion chamger to generate the heat using RDF, (3) a rotary drum which has a variable speed motor, and (4) a cyclone separator which separates the MSW from the airstream. The MSE inlet is located directly in front of the rotary drum. The waste and hot airstream flow through the drum in multipe stages, generally passing the length of the drum three times before exiting to the cyclone separator. The drum rotates constantly, agitating the waste and permitting greater surface area to be exposed to the heat.

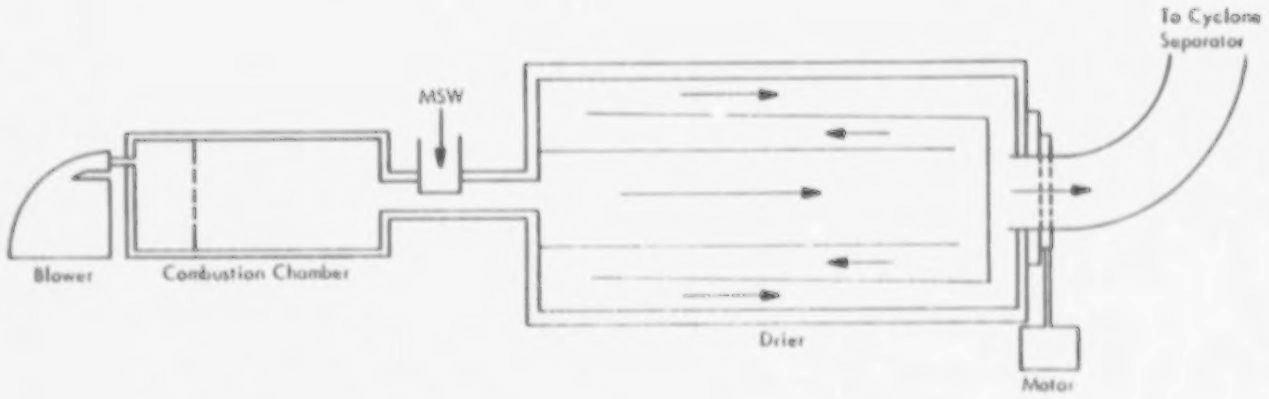

To Cyclone Separator
MSW
Blower
Combustion Chamber
Drier
Motor

Figure 35. Rotary dryer

A fluid-bed dryer, as depicted in Figure 36, consists of a jet heat source which furnishes hot gas, and a bed material to which the heat is transferred. The agitation, caused by energy waves set up by the jet heat source, increases the heat trasnfer to the bed. The bed heats the drier chamber and the MSW enters the chamber at the side. Also, a blower is used to transport the heat and the MSW, and a cyclone is used to separate the MSW from the airstream.

Experience: The El Cajon, California processing plant has a rotary dryer, and other designers are investigating the possibilities of using a dryer in their respective systems. The idea behind drying is to reduce the amount of unburnables (i.e., water) in the MSW product. To justify the incorporation of drying in the system, the cost of the equipment must be balanced by the economic value of the end product. Some manufacturers feel that the only way to make dryers attractive is to make sure that the combustion chambers are fired by the RDF, thus reducing energy costs.

It is possible that the drying process can kill bacteria and virus, but there are no data to support this theory.

Performance data on two rotary dryers and a fluidized-bed dryer are presented in the following table. The two rotary dryers are (1) a 12.2 meter long by 3 meters diameter dryer used at El Cajon, California, and (2) a 4.6 meter long by 20.3 centimeter diameter rotary dryer used in a 1972 test.[64] A fluidized-bed dryer was also tested during the 1972 research.

	Rotary 12.2 m X 3 m	Rotary 4.6 m X 20.3 cm	Fluidized Bed
Feed rate (Mg/hr)	6.7	0.05	0.45
Inlet T (°C)	107	201	146
Outlet T (°C)	54	62	--
Heat consumption (kj/mg)	1.24×10^6	1.27×10^6	--
Moisture level (%)	3.5	5	3-5

As shown in the table, there is a temperature advantage (146°C to 201°C) for the fluidized bed dryer compared to the second rotary dryer. This is due to the more efficient heat transfer through the bed medium.

There are several questions concerning dryer performance on MSW which should be research.

1. Can the dryers kill harmful bacteria and virus in MSW?
2. Does drying improve the efficiency of air classification?
3. What are the emissions from the dryers?
4. What are the costs and benefits of installing a dryer?

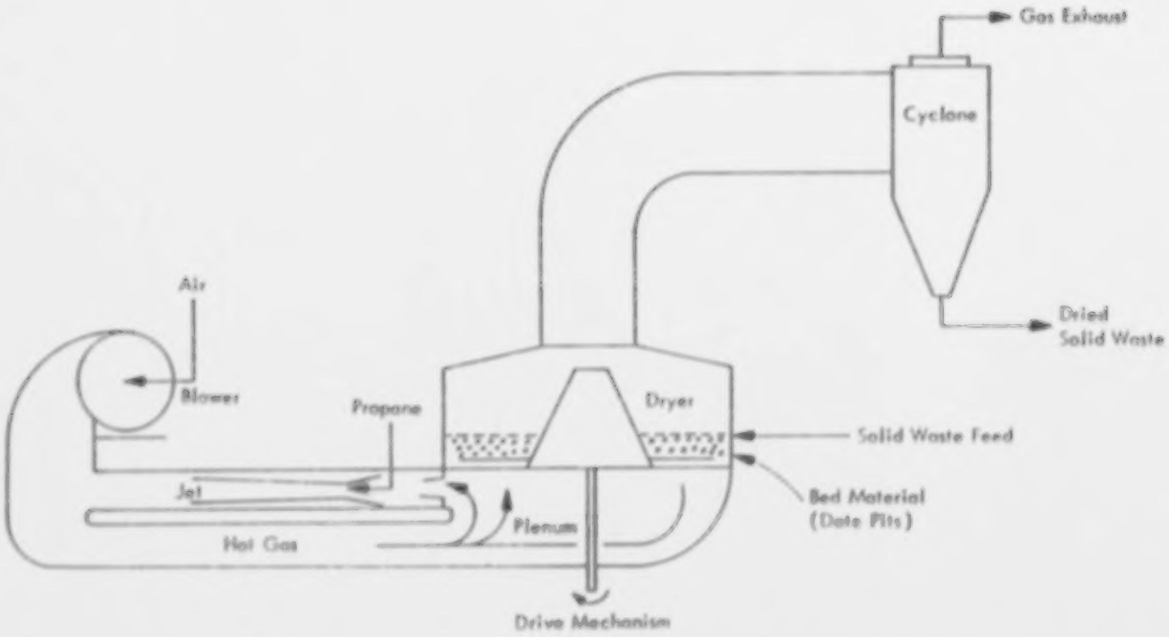

Gas Exhaust
Cyclone
Air
Blower
Propane
Dryer
Dried
Solid Waste
Solid Waste Feed
Bed Material
(Date Pits)
Jet
Plenum
Hot Gas
Drive Mechanism

Figure 36. Fluid-bed solid waste dryer.

Densifiers

Funuction: The basic purpose for the densifier is a MSW-to-energy system is to enchance the storability and/or transportability of the fuel. Also, these is an increase in energy value per unit volume. Densifiers are located at the end of the process line, before the storage and retrieval system. Densification allows more MSW fuel (by weight) to be stored in the same volume.

Description: There are five pieces of equipment which can be used to densify MSW: pelletizers, briquetters, cubetters, extruders, and compactors. Each piece of equipment mentioned applies force to reduce comparatively large volumes of MSW into smaller volumes.

Pelletizers, shown in Figure 37, are constructed in a cylindrical shape. The cylinder has holes in it to act as a die. The MSW is fed into the chamber, usually using a screw feeder, and two rotating rollers within the cylinder force the material through the die. Blades surrounding the exterior of the die-cylinder are used to cut the pellets to size.

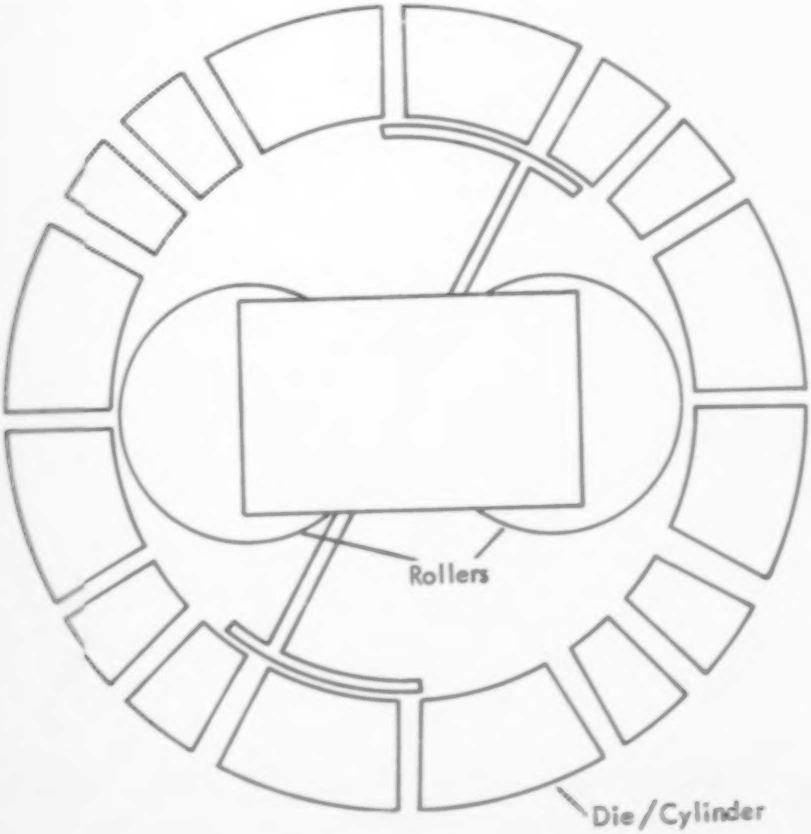


Figure 37. Pellet mill (roller and die section).

A briquette is formed by forcing the material into a mold. Generally, this is accomplished by passing the MSW between two rollers, on which individual molds of various sizes are mounted.

For cubing, the MSW is forced through square dies by rollers

Extruding is the process of feeding the MSW into a cylinder of substantial size, then forcing the waste through a cylinder of much small size, resulting in a long tube of MSW being discharged from the cylinder.

Compactors are used primarily to compress RDF into transport trucks. The RDF is fed into a large chamber, the chamger feed-door is closed securely; a ram in the end of the chamber moves forward via hydraulic motors and compacts the refuse into a fraction of its original volume. A compactor is illustrated in Figure 38.

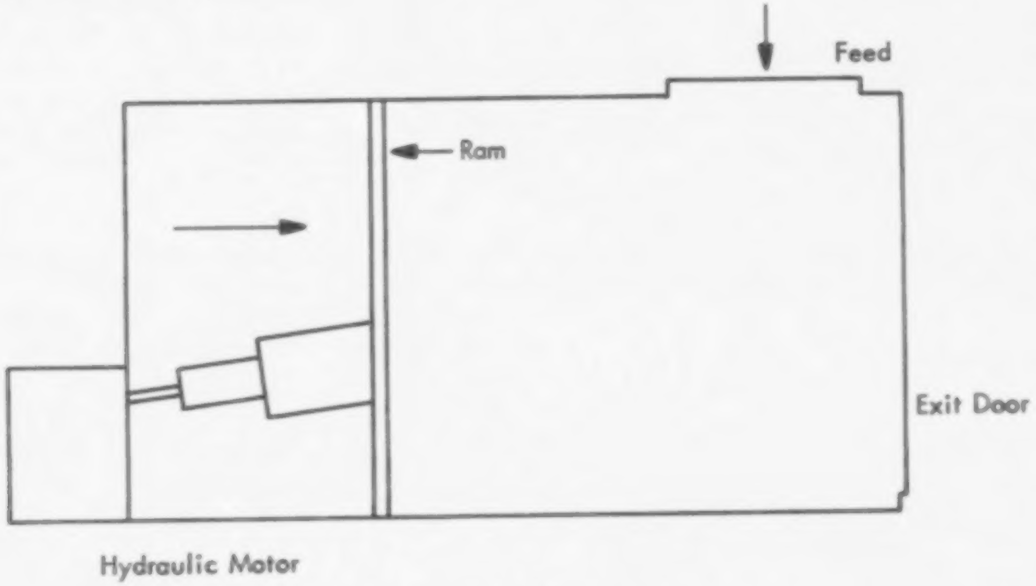


Figure 38. Compactor.

Experience: Table 10 lists types of densifiers used at present and planned waste-to-energy systems. NCRR has done some preliminary studies on densification.[134] They looked at pelletizing, briquetting, cubing and extrusion. Two other firms have investigated pelletizing.[47]

TABLE 10. TYPES OF DENSIFIERS USED AT WASTE-TO-ENERGY SYSTEMS

Location	Type
Baltimore County, Maryland	Compactor and pellet mill
Chicago, Illinois	Compactor
Milwaukee, Wisconsin	Compactor
St. Louis, Missouri	Compactor
Washington, D.C.	Pellet mill

Some sources indicate that densification of MSW cannot be accomplished without the use of binders. However, at least one firm has successfully made pellets wihout a binder by controlling temperature and pressure. A pelletizer has the effect of a grinder in two ways: (1) the roller and die are in contact, and wear against each other, and (2) the mill reduces the particle size. Therefore, steps must be taken to minimize the size reduction of the MSW and the resulting wear on the pellet mill.

The following table shows some limited data on pellets made by Elo and Rhodes[47] by an industrial firm that preferred not to have its name used.

	Elo and Rhodes Pellet 1	Industrial Pellet 2
Size	6 mm x 25.4 mm	Variable
Density	481.2 kg/ms	--
Kilojoule/kilogram	15,319	18,103
Percent of moisture	--	6
Percent of ash	--	18.2
Percent of non combustibles in ash	--	99.6
Btu/kilogram of ash	--	66

There is interest in briquetting as a future densifying process, but there are some problems. The low density of MSW makes briquetting difficult. It will probably be necessary to use a binder and have a comparative small shred size (under 6 millimeters). However, this adds a great deal of expense. Due to feeding problems of MSW through briquetters, the capital costs-to-capacity ratio is quite high. It would be necessary to increase capacity (cost remaining the same) to make briquetting attractive.

There are many questions to be answered concerning densification, which include:

1. Need for binders.

2. Particle size requirements.

3. Composition effects.

4. Moisture effects.

5. Storability and transportability.

6. Costs versus benefit.

Compactors are installed at St. Louis, Missouri, Baltimore County, Maryland, and Milwaukee, Wisconsin. They were installed to improve transportability of processed RDF to the boilers where it is to be used. No performance data are available.

Receiving Facilities

Function: The purposes of receiving facilities at resource recovery plants is to: (1) receive the raw MSW from the packer trucks or other delivery vehicles. (2), temporarily store the MSW, (3) remove undesirable materials, and (4) feed the MSW into the processing system.

Description: The incoming delivery trucks with their loads of MSW are weighed on platform scales, which are usually built into the outside roadway or the floor of the receiving building. The scale platform may be large enough to accomodate the entire truck, or each axel may be weighed separately and totaled. The tare (empty weight) of the truck is subtracted from the total weight to obtain the net weight of the MSW. The weight data are recorded either manually or automatically, depending on the sophistication of the scale.

After being weighted, the truck is drived to the receiving area where the waste is dumped. The MSW receiving area may be either the floor of the building or large pits into which the waste is dumped. In most plants, conventional rubber-tired wheel loaders are used to push the waste from the main pile into the feed conveyor which is rece-sed into the floor of the receiving area. In one plant, the receiving pits are equipped with hydraulic rams which push the waste onto the conveyors. Prior to feeding the MSW onto the conveyor, any materials which cannot be processed are manually removed. Typical layouts of receiving facilitys are shown in Figures 39,40, and 41.

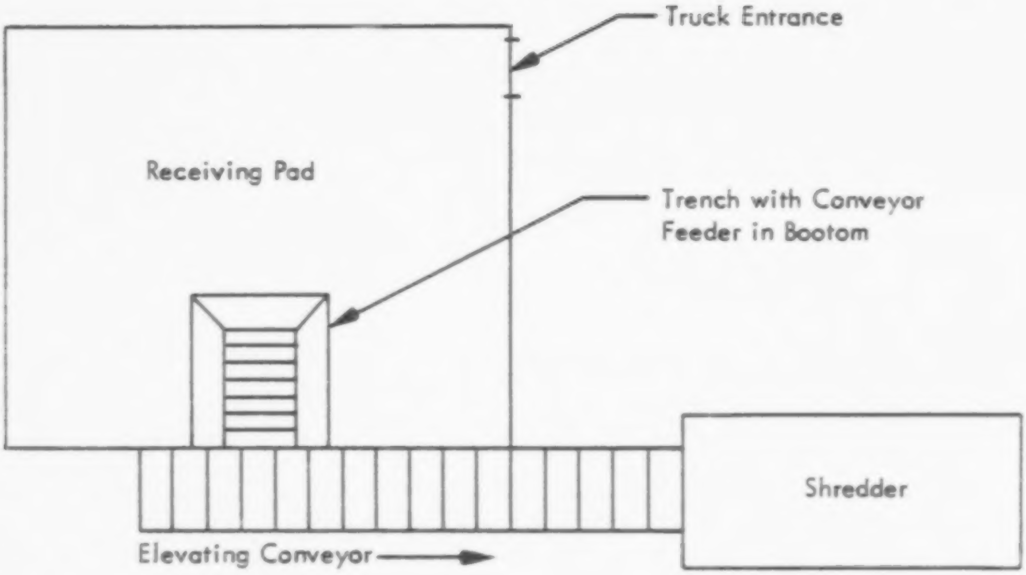

Truck Entrance
Receiving Pad
Trench with Conveyor Feeder in Bootom
Shredder
Elevating Conveyor

Figure 39. Layout of a solid waste receiving facility with floor pad receiving area.

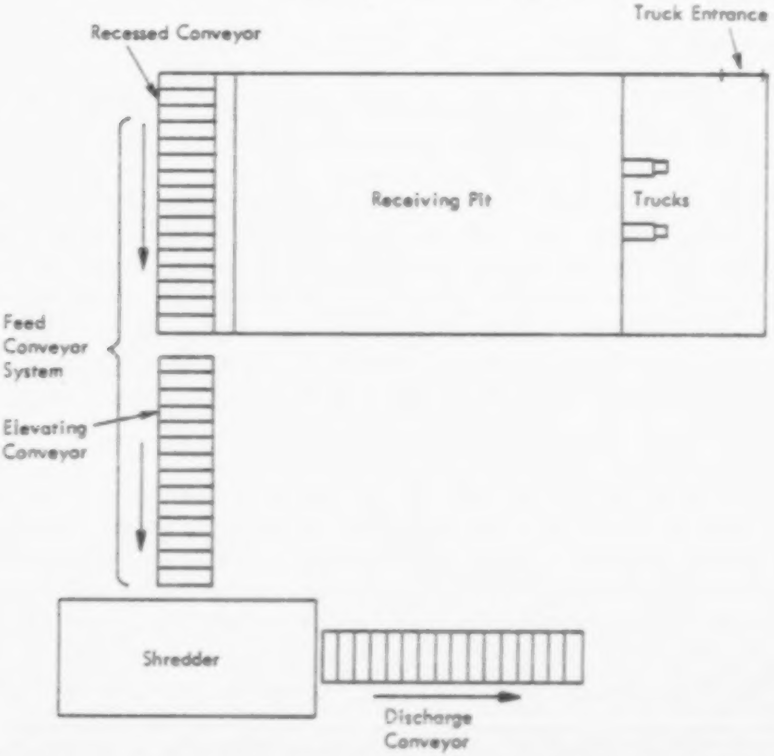

Recessed Conveyor
Truck Entrance
Receiving Pit
Trucks
Feed Conveyor System
Elevating Conveyor
Shredder
Discharge Conveyor

Figure 40. Layout of a receiving facility with receiving pit.

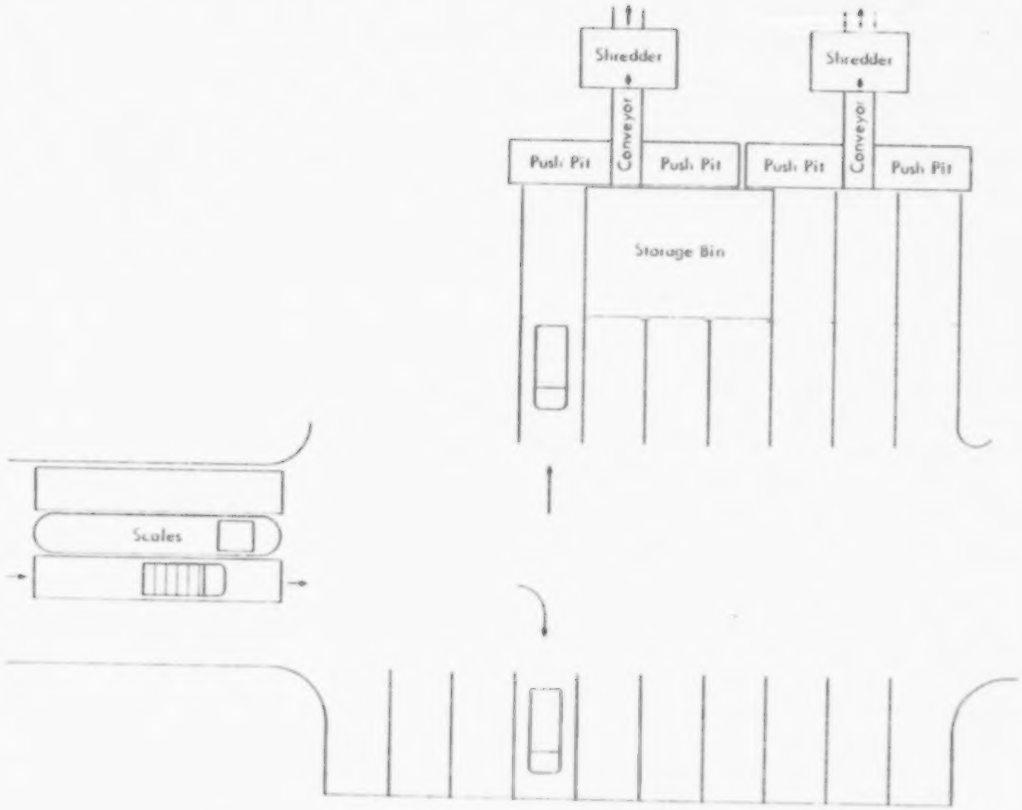


Figure 41. Push-pit receiving facility.

Experience: There have been many years of experience in weighing refuse trucks, associated with landfills and incinerators. As a consequence there are no known significant problems with truck scales for waste-to-energy systems. The system designer and user need only decide on the type and special features desired, elected a reliable manufacturer, and see that the unit is properly installed, operated, and maintained.

There are some important unanswered questions about the receiving area. It is presently not known whether it is best to use: (1) receiving pads or pits, and (2) wheel loaders or hydraulic rams. Alos, the optimum design of the receiving area and building from the standpoint of efficient truck traffic, air pollution, and noise levels has not been well established.

Conveyors

Function: Conveyors are used as a transportation system between unit operations. They do not add to the refinement process but allow refinement to be accomplished in a smooth, continuous process line.

Description: There are four basic types of conveyors used in MSW plants: belt, flight, vibrating, and pneumatic.

Belt conveyors are constructed of several plys of various materials (rubber, nylon) similar to a tire. Idler rollers are used to guide the belt. The idlers can be set at an angle to create a trough. Due to the high revolutions per minute ratings of motors used to drive conveyors, speed reduction equipment must be supplies. The motor drive is connected to a pulley which actually moves the belt using the forces of friction and the torque created by the motor.

There are several varieties of conveyors which can be included under the heading of flight conveyors, which is a general category including those conveyors which have "pocket" implements (e. g. buckets, pans, etc.). Pan (apron) conveyors, are frequently used as initial feeder in MSW processing operations. The pans overlap to prevent leakage. Leakage can also be prevented by using a piano hinge conveyor. Flight conveyors are made of steel and the drive mechanism is generally a chain and sprocket.

Vibrating conveyors operate on a stroke principle similar to reciprocating vibrating screens, described earlier. The stroke action can range from a fraction of an inch to several inches. The force acts on an angle (20 degrees to 45 degrees) relative to the horizontal plane. The material actually leaves the surface and lands at a forward point. This type of conveyor is often used to accomplish even feeding into a piece of equipment (e.g., air classifier).

Pneumatic conveyors run on the same negative/positive pressure principles as air classifiers, described earlier. Negative pressure pneumatic conveyors are often used to transport RDF to storage bins and boilers. Negative systems are usually best suited for transporting materials from multiple sites to one site, with a rotary airlock necessary to accomplish discharge. Positive pre-sure systems are usually utilized to transport from one locale to multiple locales. Negative airflow systems have fewer leakage problems, since all the leakds are inward. It is easier to unload trucks with a vacuum system and when the air-to-particle ratio is greater. Air transport systems need strict velocity and airflow controls. Also, they consume more energy than mechanical conveyors.[65,205]

Experience: In assessing experience with conveyors, several points must be carefully considered:

1. Cleanliness

2. Metering capabilities

3. Jamming

4. Effects of MSW characteristics

Table 11 lists the types of conveyors used in waste-to-energy systems.

TABLE 11. TYPES OF CONVEYORS USED AT WASTE-TO-ENERGY-SYSTEMS

Ames, Iowa	Flight, pneumatic, vibrating
Baltimore, Maryland	Flight
Baltimore County, Maryland	Flight, belt
Charleston, West Virginia	Belt
Chicago, Illinois	Flight, belt, pneumatic
El Cajon, California	Flight, belt
Milwaukee, Wisconsin	Apron
Riverside, California	Vibrating, belt
St. Louis, Missouri	Belt, vibrating, flight
Southgate, California	Belt, flight
Washington, D.C.	Pneumatic, belt

Pneumatic conveyors are used at St. Louis, Missouri; Ames, Iowa; and at Chicago, Illinois. At Ames, pluggage has occurred due to the moisture content and matting characteristics of MSW. The plugs were removed using "sewer jets." Also, the conveyor liners have worn out at the elbows; the worn areas become rough and catch light material as it passes. These liners are being replaced with more resistant material which retains its smooth surface longer. Additionally, the airflow had to be increased due to uneven feeding into the transport system.

Flight conveyors are used for transporting raw or shredded MSW. They are used at Ames, Iowa; Baltimore, Maryland; Chicago, Illinois; El Cajon, California; and Milwaukee, Wisconsin. As mentioned before, cleanliness can be accomplished with Z-pan, piano hinge, or overlapping pan constructions. Some MSW can still spill over the sides, but flight conveyors can be built fairly wide, with skirts and dribble pans. The flights have a high degree of impact resistance, fire will not damage them, and maintenance is negligible.

Either inboard or outboard rollers can be used. Outboard rollers allow the weight to be distributed over a greater area and thereby permit larger loads to be conveyed. Maintenance is also easier. The rollers generally wear out faster than the chain and, with outboard rollers, the roller can be replaced without removing the chain.

Jamming of flight conveyors has been experienced at several facilities. Often the disruption was caused by problems with a down-line piece of equipment (e.g., rejects from the shredder). In systems where two angles are needed, manufacturers have found it better to use two conveyors. The first should have the lesser angle. The second (steeper angle) should be run at a higher speed. This relieves the jamming effect caused by material slippage when one conveyor is used. Problems of under powering have also caused slippage and jamming. Manufacturers are specifying greater power requirements to solve this problem. Manufacturers state that angles up to 40 degrees can be used without creating a slippage problem, if flights are installed.

Belt conveyors are used for shredded material at Chicago, Illinois; Ames, Iowa; Riverside, California; and St. Louis, Missouri. Belt conveyors have a cleanliness problem. Slide-backs occur on inclines and the idlers cause unwanted agitation and spillage problems. Skirts and dribble pans can be installed to help the situation. Belt conveyors are prone to damage from impacts of objects falling on the belt.

Vibrating conveyors are frequently used for transporting MSW between unit operations. They even-out the material and, for this reason, are used often for feeding unit operations (i.e., shredders and air classifiers). The vibration can cause structural problems along the process line, as well as housekeeping problems. Designers are having some problems in accurately sizing vibrating conveyors, for MSW.

Storage and Retrieval Bins

Function: Storage and retrieval bins allow a waste-to-energy plant to process large quantities of fuel and then allow the fuel to be transported when needed. Using such a system, RDF can be processed in a single 8-hour shift and burned for electrical generation on a 24-hour basis.

Description: Construction and design differences in storage and retrieval bins involve the shape of the structure and the method of discharge.

A conical "sweep bucket" bin is depicted in Figure 42. The RDF enters at the top and falls to the bin floor. The waste is transported to the bin via a pneumatic conveyor (with cyclone separator) or a flight conveyor. This intake operation is the same for most of the storage systems discussed. A "sweep bucket" arrangement is used for retrieval purposes. The end of the chain of buckets is attached to a powered ring. This allows the buckets to rotate about the pile of RDF. The buckets at the end migrate toward the center, fill and drag the waste through a discharge chute onto a conveyor. The speed of the chain is adjustable to allow control over the feed rate. The RDF is usually pneumatically transported to the next operation.

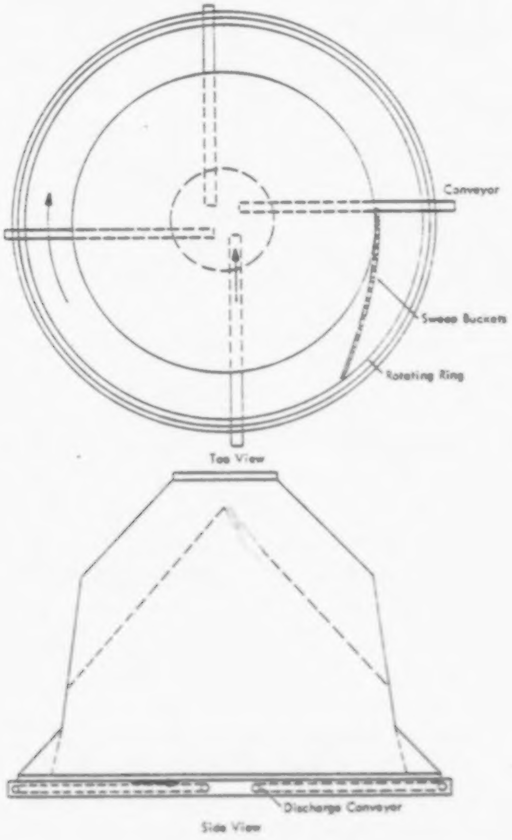


Figure 42. Conical "sweep bucket" bin.

Two other types of discharge systems could be paired with a conical-shaped bin or cylindrical silo. They both use screws. The first (Figure 43a) has the screw running the diameter of a suspended silo. The screw pivots at one end and follows a rail which is in an arc configuration on the opposite end. The waste exits from the end where the screw pitch is greatest. The second (Figure 43b) has the screw attached to a post in the center. The other end is connected to a motor which runs along a track at the outer perimeter. Discharge is from an opening at the center of the bin.

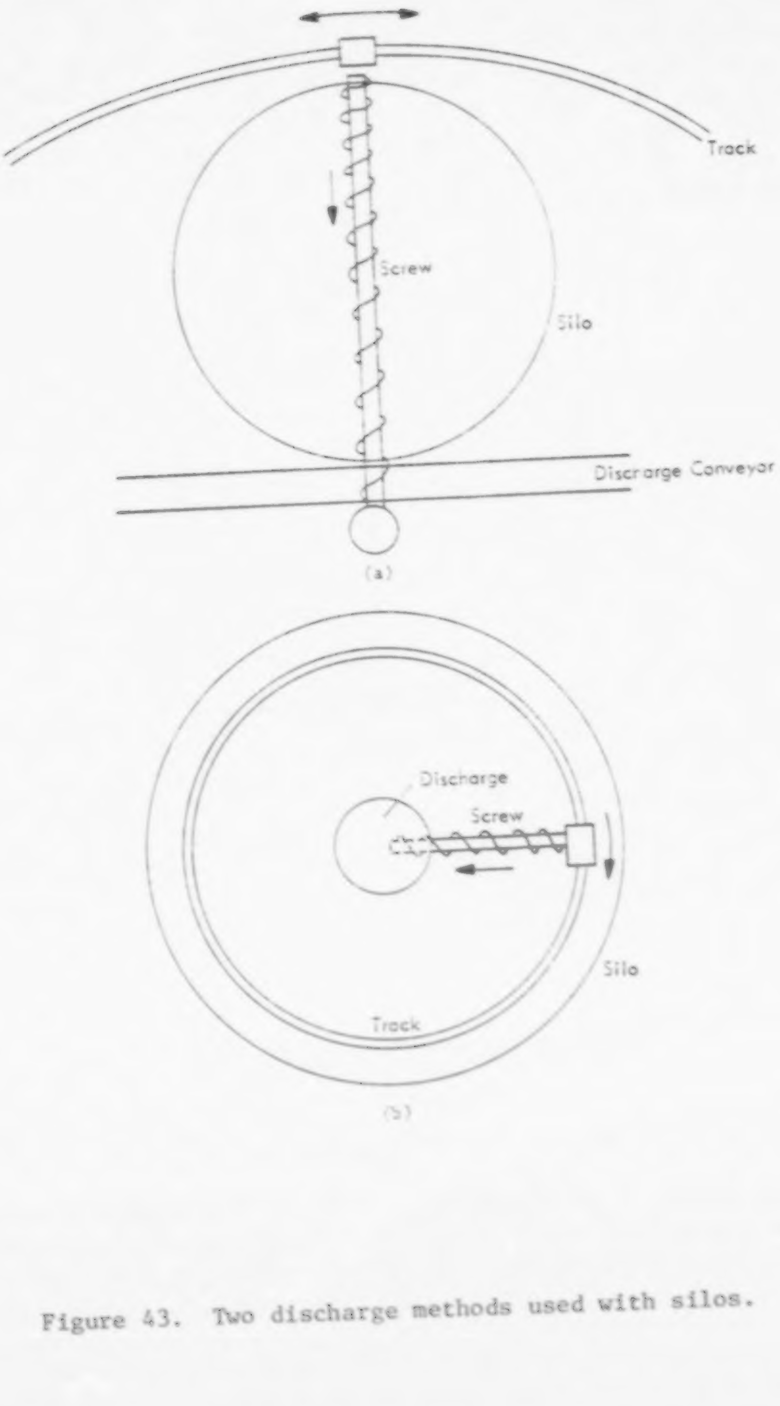

Track
Screw
Silo
Discharge Conveyor
(a)
Discharge
Screw
Silo
Track
(b)

Figure 43. Two discharge methods used with silos.

An inverted bin, shown in Figure 44, consists of inward sloping walls (4 degrees to 7 degrees), with the bottom of the bin wider than the top. This design is to help prevent bridging (see Figure 45a) of the MSW. There are three types of retrieval mechanisms that have been used with this type of bin: (1) a series of parallel feed screws with variable pitch and speed, (2) a pair of feed screws which rotate in the opposite direction and travel the length of the bin on an exterior track (Figure 44), and (3) a series of rollers which run on individual motors, enabling the operator to vary the speed of each roller (Figure 46). The discharge with the screws is at the end with the greater pitch; for the rollers, it is through the bin bottom.

A "doffing roll" bin is shown in Figure 47. The screws located in the upper portion of the bin are used to even the pile of MSW as it enters. A drag chain system in the bin floor is used to push the RDF into a group of rotating teeth. The speed of the drag chain can be manipulated to control the evacuation rate. The teeth have a fluffing effect making the waste more uniform and more easily transported.

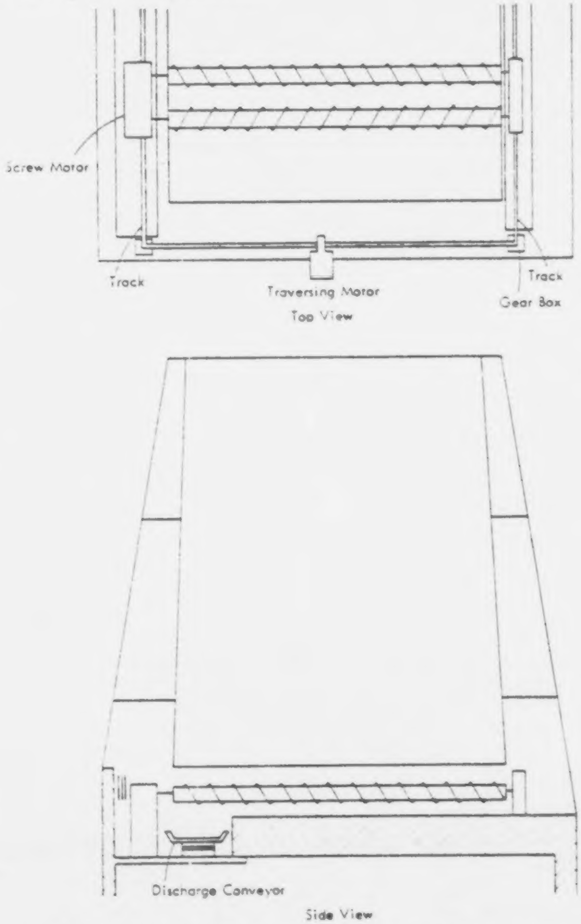
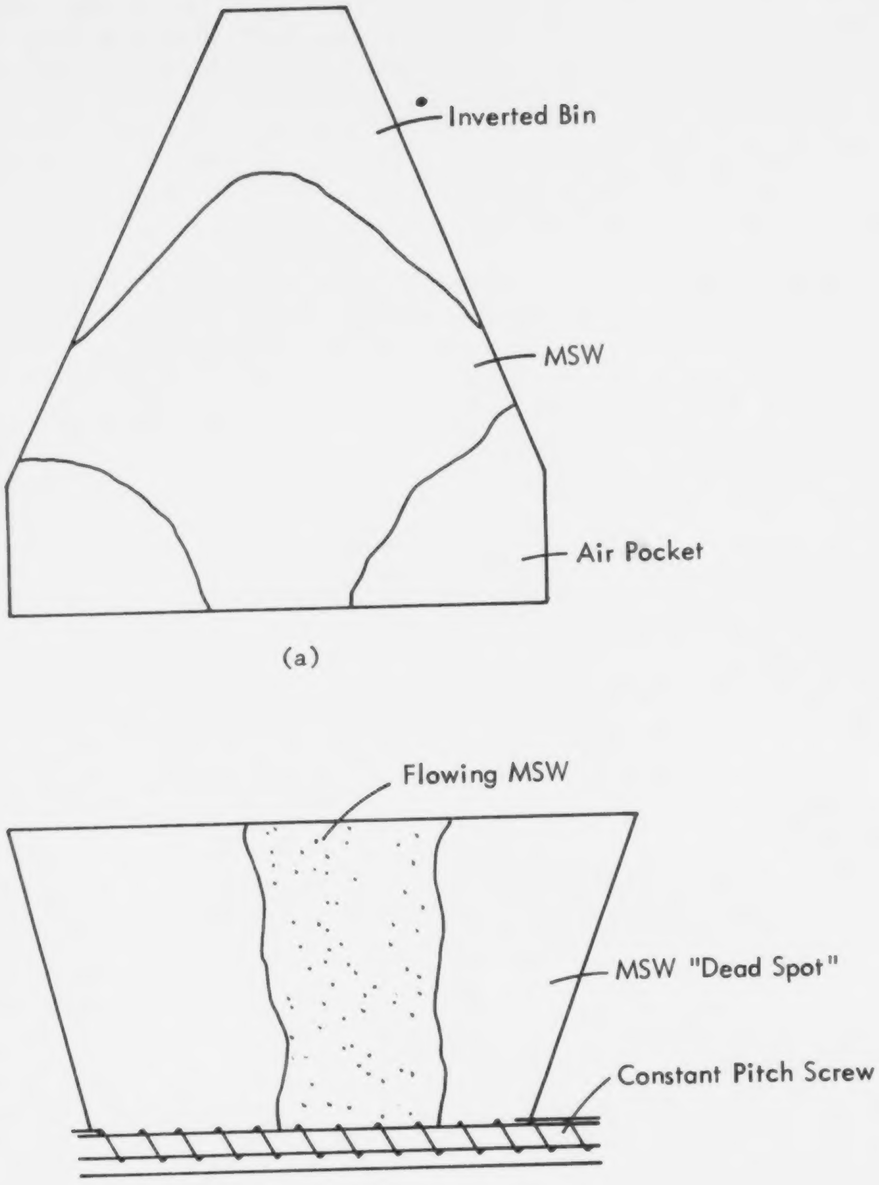


Figure 44. Inverted bin with dual travelling screw discharge.


Inverted Bin
MSW
Air Pocket
Flowing MSW
MSW "Dead Spot"
Constant Pitch Screw

(a)

(b)

Figure 45. Flow problems encountered in MSW storage and retrieval.

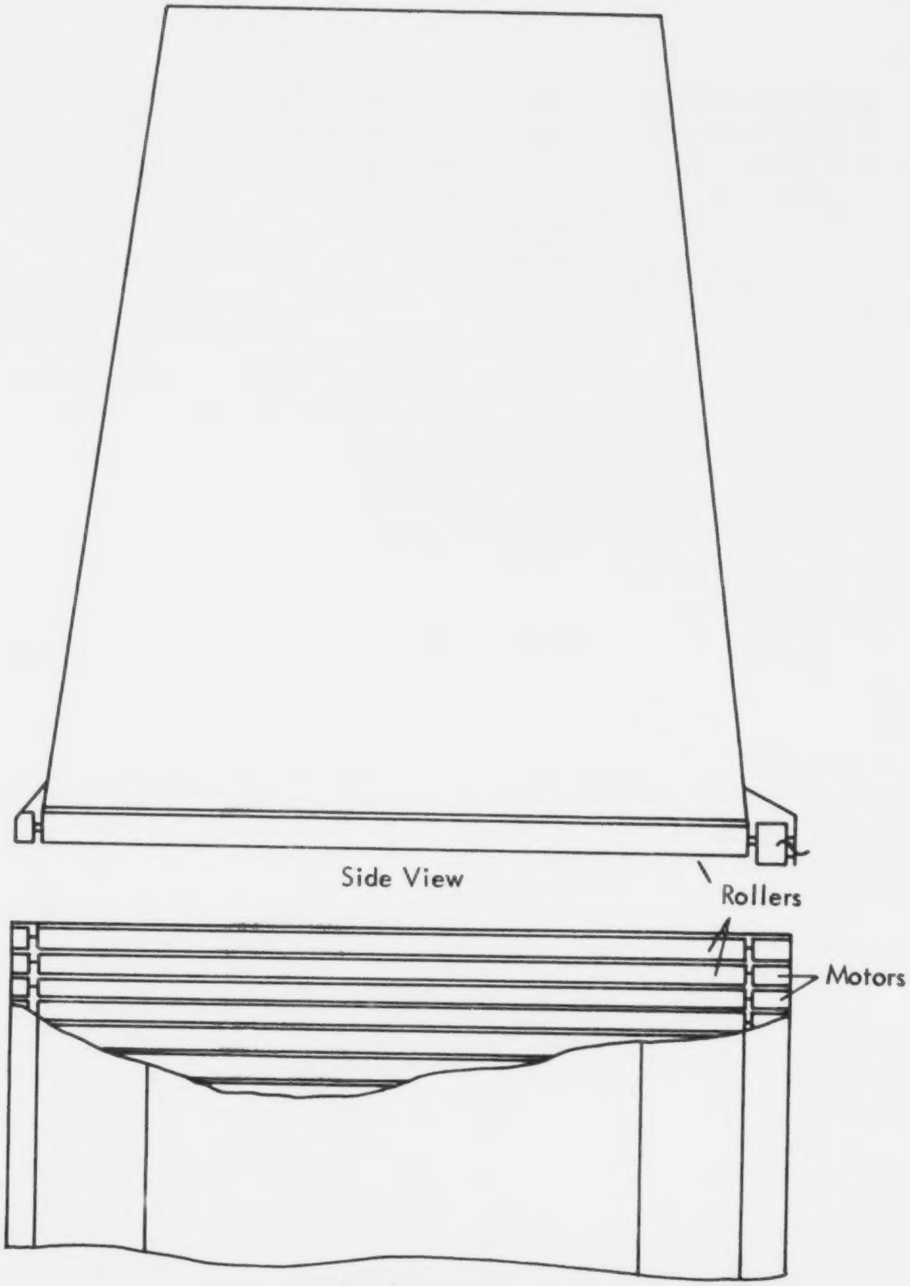
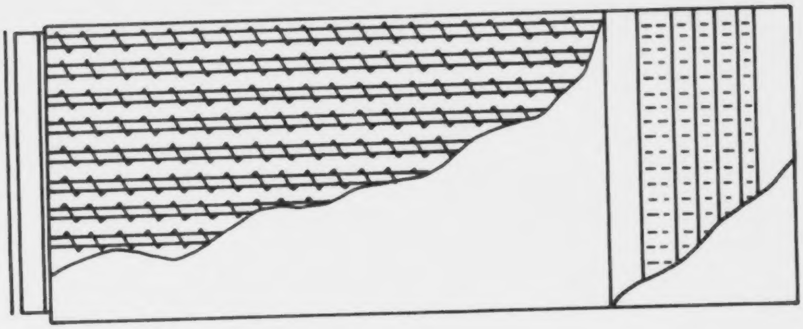
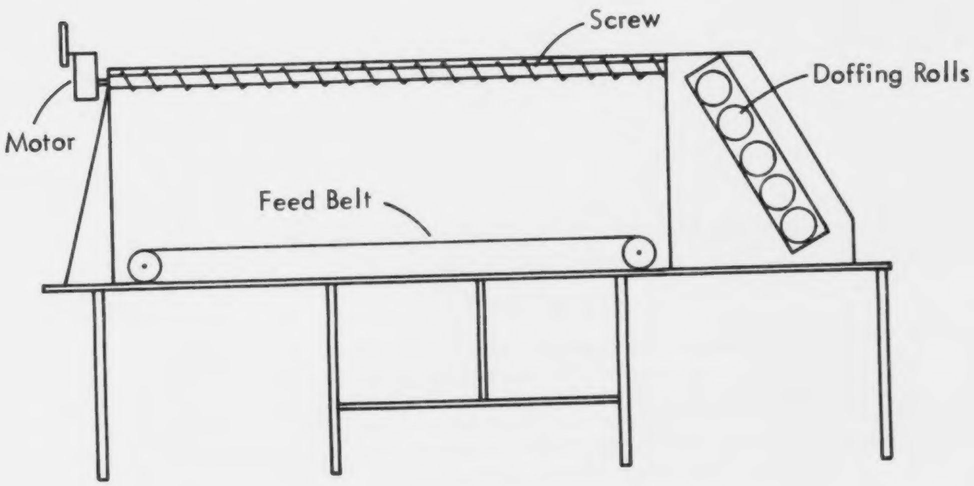

Side View
Rollers
Motors
Top View

Figure 46. Inverted bin with rollers



Top View


Screw
Doffing Rolls
Motor
Feed Belt

Side View

Figure 47. Rectangular bin with screws and doffing rolls.

The live-center bin, shown in Figure 48, is constructed so the width at the bottom is much smaller than at the top. There are a series of vertical screws used to even-out the incoming RDF and to keep it loose. Two screws in the bottom are used for discharge. The speed can be regulated to control the rate of discharge.

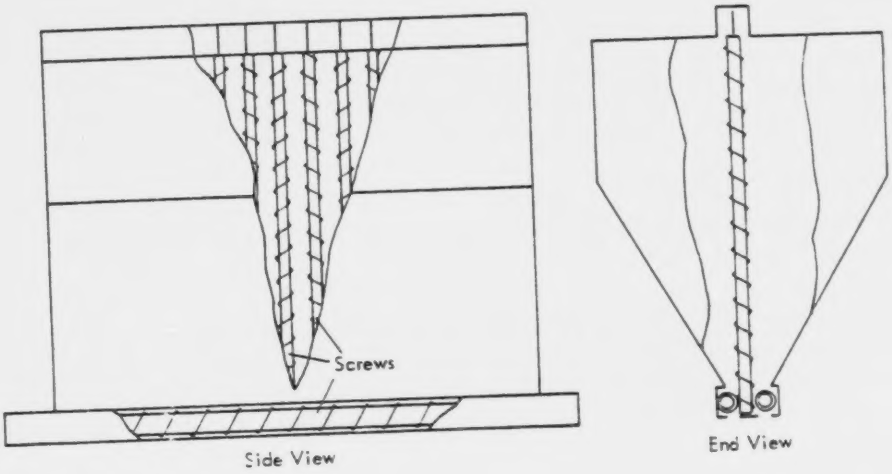


Figure 48. Bin with vertical and horizontal discharge screws.

Experience: Table 12 lists the types of storage and retrieval systems in use or planned.

TABLE 12. TYPES OF STORAGE AND RETRIEVAL BINS AT WASTE-TO-ENERGY SYSTEMS

Location	Bin Type	Discharge Type
Ames, Iowa	Conical	Sweep-bucket
Baltimore, Maryland	Conical	Sweep-bucket
Chicago, Illinois	Conical	Sweep-bucket
El Cajon, California	Rectangular	Scews and doffing rolls
Riverside, California	Inverted	Rolls
St. Louis, Missouri	Inverted	Dual screws

At St. Louis, Missouri, an inverted bin with screw discharge was used. Results have been termed as satisfactory. Some bridging occurred, but it was not considered significant. The walls at the bottom of the bin started bulging, due to the "avalanche" effect of the collapsing MSW. The problem was corrected by adding stiffeners to the outer wall surfaces. Also, the original motor was not large enough, and the screws were unable to turn, due to the high frictional forces of the material. A larger torque motor solved this problem.[54]

Riverside, California, plans to use an inverted bin with roller bottom discharge. The designer claims that all the bin structure is useful storage space; controlled feeding is easily accomplished; the inward sloping walls prevent bridging; the power usage is minimal; and the motors used supply greater torque action. Presently, no performance data are available.

The "doffing roller" bin is used at El Cajon, California, as a small (1-hour) storage bin. However, performance data are not yet available on this type of bin.

Manufacturers of the vertical/horizontal screw bin claim that this mechanism will prevent bridging, will even and mix the contents of the bin, and that no concrete foundation is necessary. The vertical screws must rotate when the bin is being charged or discharged. However, no performance data are available.[144]

The pitch of the screw in all screw discharge mechanisms has a direct effect on a discharge performance. Using a constant-pitched screw, "dead" spots (Figure 45b) will occur. There will be a freer flow using variable-pitched screws.[90]

There is a need for more data concerning bridging, compaction, even/controllable retrieval, moisture effects for MSW storage and retrieval bins.

Dust Controls

Function: The function of a dust control system is to minimize the release into the atmosphere of dust created by MSW processing. Dust comes from two basic sources: the raw MSW itself (ash, fines, fibrous material, etc.) and the dry refinement processes (shredding, air classification, etc.).

Description: Three types of equipment are used in waste-to-energy plants for dust control: cyclone separators, bag-houses, and wet systems.

Figure 49 depicts a cyclone separator and its internal actions. The dust-laden air enters near the top of the inverted cone vessel. The air spirals down the vessel and returns to the outlet (at the top) in the reverse manner. This creates centrifugal forces which power the particles to the outside of the vessel. Gravity then causes the dust to fall. The particular cyclone shown has a "stack" to deflect any dust remaining in the outlet airstream. Cyclone efficiency is dependent on airflow, velocity, pressure, the diameter and the length of the cone.

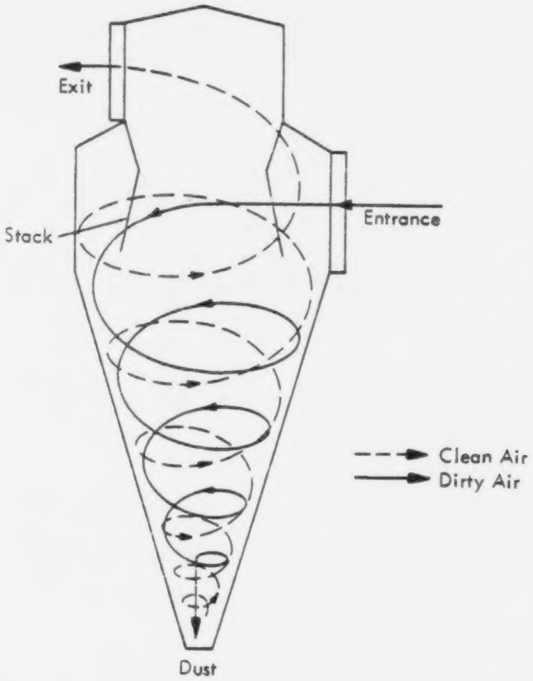


Figure 49. Principle of a cyclone separator.

Bag-houses are a series of cloth filters aligned in a housing. The structure may be either circular, as shown in Figure 50, or rectangular, as shown in Figure 51. The dust laden air enters the housing near the bottom, where heavy particles fall out immediately. The air then flows upward and passes through the filter bags, with dust adhering to the outsides of the stream jetted in the reverse direction through the bags. The air-to-cloth ratio has a significant effect on the efficiency of the device. Both cyclones and bag-houses are operated by negative or positive-pressure air transport systems.

One type of wet dust control is a scrubber dust collector, which is illustrated in Figure 52. The dust-laden air enters at the top portion of a long cylinder. The inlet is tapered, with an adjustable device to control

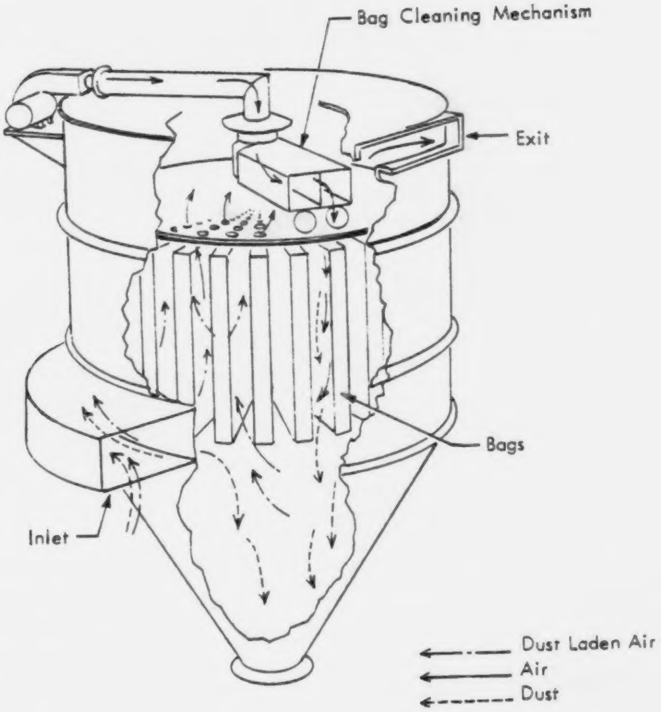

Bag Cleaning Mechanism
Exit
Bags
Inlet
Dust Laden Air
Air
Dust

Figure 50. Circular Baghouse.

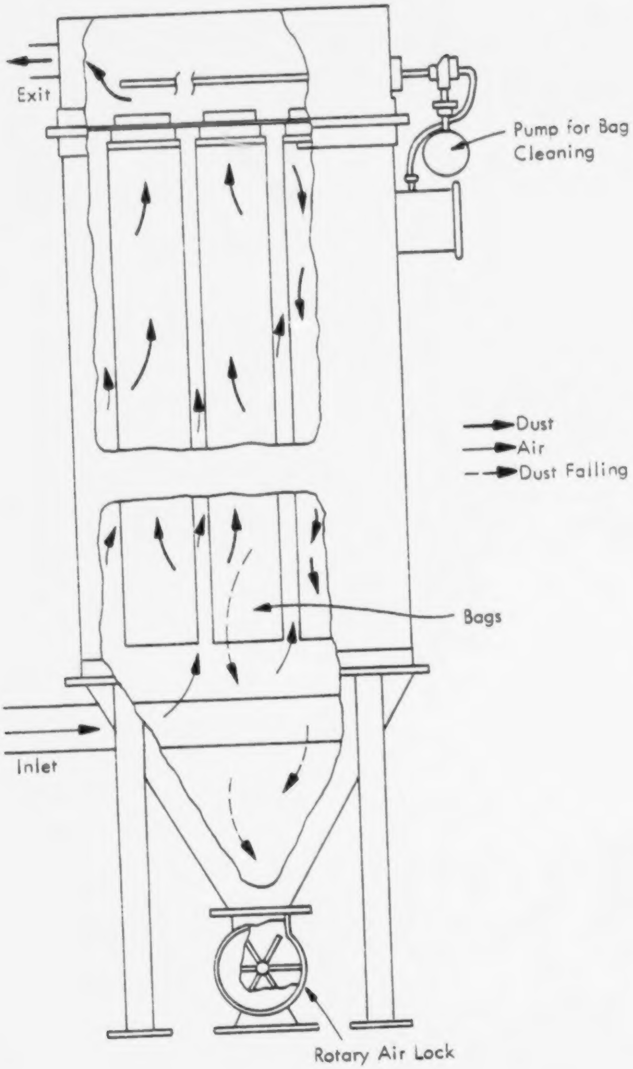

Exit
Pump for Bag Cleaning
Dust
Air
Dust Falling
Bags
Inlet
Rotary Air Lock

Figure 51. Rectangular Baghouse

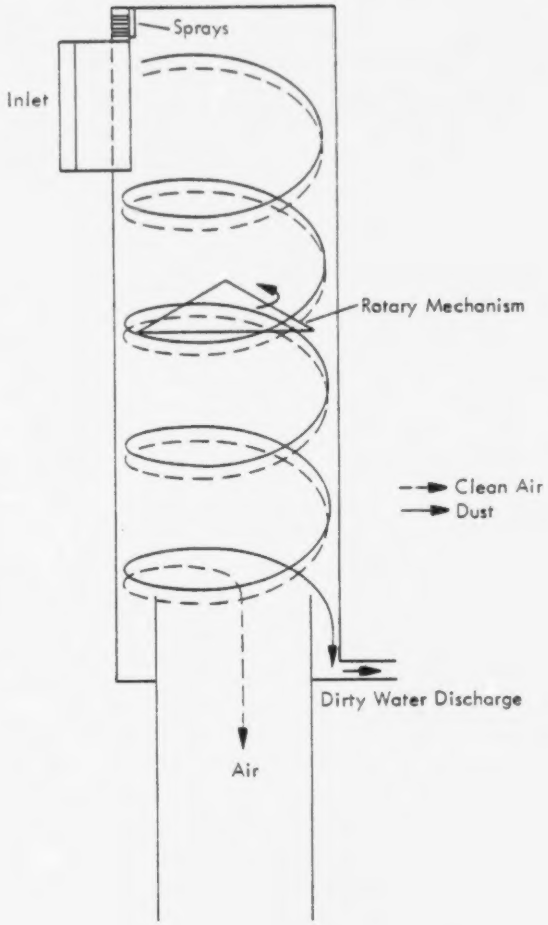

Sprays
Inlet
Rotary Mechanism
Clean Air
Dust
Dirty Water Discharge
Air

Figure 52. Wet scrubber dust collector.

air velocity, located at the end. Liquid is injected near the top of the vessel in a fine mist, which collects the dust particles. The dust-laden mist and the air are forced to the outer portions of the vessel by a rotating mechanism which creates a centrifugal air pattern within the cylinder. At the bottom of the cylinder, a concentric tube extends several centimerts into the vessel. The air leaves via the inner tube and the dusty water leaves by the outer cylinder. Another MSW wet dust control is to moisten the waste sufficiently to prevent a dust problem; e.g., by inserting water sprays in the hammermill.

Experience: Table 13 lists the types of dust control systems at the various waste-to-energy facilities. The St. Louis, Missouri, pilot plan is an outdoor operation, and the dust problem has not been obvious. However, it has been found that there is a significant amount of particulate emissions from the processing equipment. At Ames, Iowa, the system is housed in a building, and the dust problem is significant.

TABLE 13. DUST CONTROLS AT WASTE-TO-ENERGY SYSTEMS

Location	Type
Baltimore, Maryland	Cyclones
Baltimore County, Maryland	Baghouse
Chicago, Illinois	Bag filter
East Bridgewater, Massachusetts	Bag filter
El Cajon, California	Wet system
Pompano Beach, Florida	Cyclones and Bag-house
St. Louis, Missouri	Cyclones
Palmer Township, Pennsylvania	Closed system

Bag-houses are used at the Baltimore County, Chicago, and East Bridgewater plants. East Bridgewater has the bag-house connected to all unit operations, and the plant is equipped with a grounding rod to prevent any adverse effects from static charges. All of these bag houses use reverse airstreams to allow cleaning of the bags without shutting down the entire system. Presently, however, there is no performance data available.

Bag filters are reported to have a high efficiency, although there are no supporting data available for MSW. It is known that the efficiency is affected by the shape of the bag. The top-load type of bag-house reduces maintenance time involved in changing damaged bags, while side-door types do not allow total accessibility to the bags.

The wet-jet dust control concept may be effective but ti requires a drying system to insure that the energy value of the fuel is not adversely affected. Water sprays might also have adverse effects on the equipment (e.g., corrosion) and its function (e.g., separation efficiency in an air classifier) El Cajon uses such a system, employing water sprays over the primary shredder discharge conveyor. Data on the efficiency of these wet dust control systems are not available. To date, no waste-to-energy system has installed a wet scribber on the processing equipment.

Electrical Controls

Function: Electrical controls refer to the electrical system through which the various pieces of equipment--shredders, conveyors, etc.--are controlled.

Description: Thus far, the information obtained concerning electrical controls is sketchy and incomplete. More detailed information must be collected before specific data on electrical control systems at municipal solid waste-to-tnergy plants can be developed.

Discussions with MSW plant designers indicate that the electrical control systems are custom designed installations for each plant and vary widely in degree of sophistication. Those designers who have taken a minimal approach rely on simple, more manual types of instrumentation and control. Other plants, such as Baltimore County, Maryland, have highly automated control systems. Closed circuit television is used in some instances to monitor operations that are not readily accessible or are dangerous for personnel. Two-way radio communication systems are also being utilized. At some plants, visual monitoring of the refuse flow is done from a glass-enclosed control booth where the operator has a good view of the unloading activities and other parts of the plant.

Baltimore County, Maryland, has a control system which uses a computer for testing and control functions. The system was developed by the plant designer. Data from various pieces of equipment (e.g., weight from scales, amps from shredders) are fed into the computer; such data can be recalled from the data banks at any time. The computer system has built-in safety ranges for various parameters for the different pieces of equipment. If trouble arises, the "fault" indicator light on the control panel will indicate the particular piece of equipment which is malfunctioning. The computer will also activate shutdown procedures.

A small control panel, shown in Figure 53, is in front of each operator and rotates with the booth. The upper portion of the panel has indicator lights showing the operational condition of the equipment listed. The lower left portion has the push pit controls; the bottom center and bottom left are controls for the input conveyor and shredder. These two pieces of equipment can be controlled manually or automatically. A key lock can be activated so the system is not mistakenly started (e.g., during repairs). The center of the panel has indicator lights for fire and operating mode, buttons to activate emergency equipment, and buttons to start and stop the grappling crane. This crane, used to remove unshreddables from the input stream, is controlled by the operators (via levers on the side of the control panel) the transfer bridge controllers in the receiving area. The rest of the plant is monitored by closed circuit television.[16]

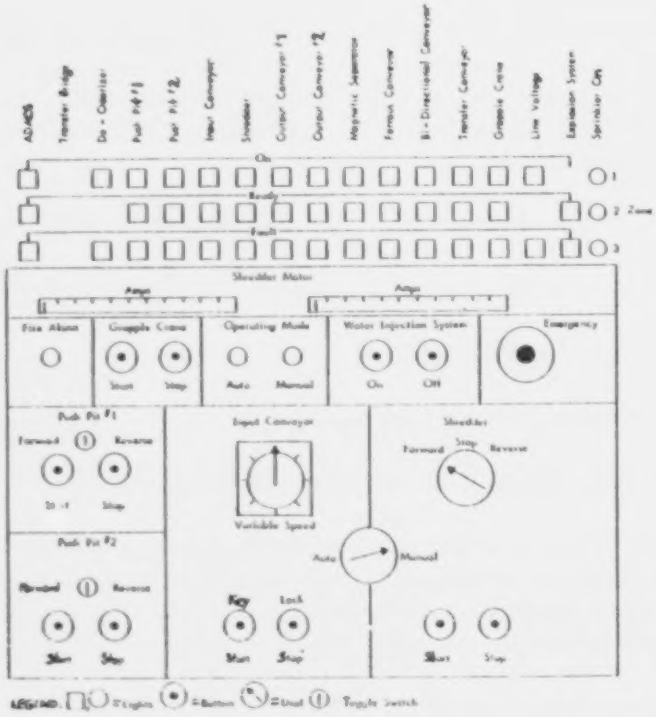

Transfer Bridge
De-Odorizer
Push Pit #1
Push Pit #2
Input Conveyor
Shredder
Output Conveyor #1
Output Conveyor #2
Magnetic Separator
Ferrous Conveyor
Bi-Directional Conveyor
Transfer Conveyor
Grapple Crane
Line Voltage
Explosion System
Sprinkler On
On
Ready
Fault
1
2 Zone
3
Shredder Motor
Amps
Amps
Fire Alarm
Grapple Crane
Start
Stop
Operating Mode
Auto
Manual
Water Injection System
On
Off
Emergency
Push Pit #1
Forward
Reverse
Start
Stop
Push Pit #2
Forward
Reverse
Start
Stop
Input Conveyor
Variable Speed
Auto
Manual
Key
Lock
Start
Stop
Shredder
Forward
Stop
Reverse
Start
Stop
LEGEND: = Lights = Button = Dial Toggle Switch

Figure 53. Baltimore County, Maryland, control panel.

At the Charleston, West Virginia, plant a minimal approach has been taken in regard to controls and instrumentation. Also, there have been numerous additions and modifications to the original electrical equipment. Most of the monitoring devices consist of rather simple, direct visual read-out information.

At El Cajon, the front-end equipment is in the receiving building. The operator watches the receiving floor, shredder, and storage area from an air-conditioned, glass-enclosed cubical located above the floor level. From this control booth, the operator can control the conveyors and the shredder. The operator also has a read-out on his control panel from the scale where incoming trucks are weighed. The operator signals the driver to proceed or to stay at the scale area until he is released to go into the plant.

There are three separate motor control centers at the El Cajon installation. The primary shredder operates on 2.300 volts. There is a separate motor control center for the shredder. This motor control center, specified as "NEMA Class E-2 Medium Voltage," is in a separate prefabricated metal building void of any combustible gas. Except for the primary shredder and one gas compressor operating in 2,300 volts, most of the rest of the plant operates on 400 volts.

The designer of the City of Baltimore, Maryland, installation considers much of the information on the control system proprietary. The electrical control system is their own design. Closed circuit television cameras are used to monitor some operations, like shredders and other areas that are dangerous and not readily accessible.

The various trouble indicators in the control system include:

- Indicators to tell whether a shaft is turning.
- Motor amperage regulators.
- Level indicators of various kinds.
- Pressure indicators that measure vacuum or pressure to activate relays.

The primary speed is controlled by the amperage on the primary shredder. The designer's opinion is that the amperage controller "feels" the refuse stream better than the operator can. The operator has an override, and if there is a problem he can manually effect a stop.

Fire and Explosion Protection

Background: MRI has learned of several incidents of explosions and fires in municipal solid waste plants. In addition, all of the shredder manufacturers contacted had expressed concern over the possibility of explosions occurring when mixed municipal waste enters the shredder.

The research conducted to date indicates that fires in the shredding phase of the system are the rule rather than the exception. The existence

Also, the larger pieces of metal, which stay in the shredder longer, sometimes become red hot. When the hot metal falls into the shredded material, a smoldering type of fire can easily develop. One opinion expressed by a plant designer was that the small smoldering type of fire is usually handled best by simply locating the source of fire, pulling it out and spraying it with a water hose.

An additional consideration in regard to fire hazard is that many of the conveyors are of rubber construction. There have been instances of conveyor belts catching fire. There have also been reports of fires in other areas besides the shredder area; e.g., in the motor starter control rooms.

Solid waste shredding plants are vulnerable to explosions because of the presence in the refuse stream of such items as gasoline cans, propane tanks, dynamite, TNT, gunpowder, and live ordinance. Another possible source of shredder explosions is hybrid dust/gas mixtures.

In assessing explosions and explosion protection, it is important to differentiate between deflagrations and detonations. The overpressurization in a deflagration occurs over a time interval on the order of 0.1 to 1.0 seconds in a typical-sized shredder--the burning takes place at a flame speed below the velocity of sound. The local overpressurization in a detonation occurs instantaneously via shockwave--the burning takes place at a flame speed above the velocity of sound in the unburned medium.

Most protective measures, discussed later in this section, are effective for deflagrations but cannot provide much protection for detonations. The major protection measures for detonations are blast-resistant construction and the isolation of personnel and expensive equipment.

The exact conditions under which a dust explosion will occur in a refuse shredder are apparently not known. However, when dust particles are small enough to be classified as powder (particle size less than 1 millimeter), a spark, hot spot, or other ignition source can ignite the dust cloud. Dust explosion hazard appears to be minimal for those shredders that are delivering a product of at least a few centimeters in size.

Although the risk factor appears low for dust explosions in the shredder itself, dust does represent a hazard in other parts of the plant. Dust/shredded refuse fires have occurred on conveyors and in dry, dust-collecting devices where the fine particles are separated from the coarser particles. Also, dust explosions would be more likely in size reduction operations where a fine powder refuse-derived fuel is being produced.

Hybrid mixtures should be considered particularly hazardous. When combustible dust and flammable gas or vapor are present at the same time in the shredder they can be explosive. Unfortunately, even small quantities of gas can combine with an accumulation of fine, combustible dust to form an explosible, hybrid mixture.

Description: The following fire and explosion measures and damage control techniques are being employed, either singly or in various combinations, at waste-to-energy plants:

1. Manual screening and segretation of incoming refuse.

2. Isolation of personnel (especially near shredder).

3. Barricades or blast mats near the shredder (to protect personnel and valuable equipment from penetration by fragments from explosions.)

4. Explosion venting.

5. Continuous water spray (in the shredder)

6. Automatic water sprinklers for conveyors.

7. Automatic water sprinklers for building.

8. Water hoses.

9. Explosion suppression systems.

10. Fire suppression systems.

11. Dust control systems.

In addition to the above measures, the following have been suggested as some additional protection techniques.

1. In plants where the control room is close to the shredder, high-strength glass or plastic (>3 psig fracture pressure) in control room windows.

2. An emergency water spray system which would inject water into the shredder before ignition, which would be activated by a flammable gas detector installed in the shredder.

3. If steam is generated at the plant, the steam can be injected into the shredder instead of a water spray.

4. Dry powder extinguishing agents, such as those presently utilized in suppression systems in Germany.

Some of these protection meansures are described in the following sections.

Screening and Segregation of Incoming Refuse: Some plant designers stress maximum front-end separation to divert hazardous materials. The presorting of incoming municipal waste is handled in several ways. In some cases, the individuals making pickups on the route are instructed not to load anything onto the truck that appears to be a dangerous material. Generally, when trucks arrive at the plant, they dump onto an unloading floor. The man operating the front-end loader is instructed to look for and segregate any hazardous items. The operator in the control room, through visual inspection of the incoming material on the conveyor as it moves to the shredder, also tries to sort out hazardous items.

However, due to the wide assortment of hazardous items and the large shredding stream capacities involved, it is virtually impossible to completely eliminate all hazardous material from entering the shredders.

Explosion Venting: Explosion venting refers to vent doors, blow off hatches, rupture discs, etc., on the equipment or building containing the explosion. The basic principle of explosion venting is that the maximum pressure developed in a deflagration can be reduced if the gases are allowed to escape from the confining structure before the combustion process is complete. To be effective, the vent area and its location in respect to the ignition source must be designed to allow the gases to escape before damaging pressure develops. In addition, the ducting used to channel the gases out of the building must be designed to prevent the recompression of gases on the way out.

Large discrepancies exist between the venting recommendations of the various designers and manufacturers. There is a need for explosion venting tests so that more accurate guidelines can be developed for equipment as complicated in shape and content as a refuse shredder.

Continuous Water Spray in Shredder: A continuous water spray is used in some refuse and automobile shredders to control dust. A fine water spray or mist has also been found to provide explosion protection. The water vapor in the shredder serves as an inerting agent. A vapor concentration of about 30 volume percent or higher will extinguish or prevent a methane-air flame. In addition the suspended water droplets are effective as a quenching medium for flame. Small, closely-spaced drops are more effective than large droplets in quenching flame.

However, the use of continuous water spray in the shredder has several undesirable side-effects. When water is absorbed by the Shredded refuse, magnetic separation of ferrous metals is more difficult; the combustion efficiency and heating value of the shredded refuse is lowered; and water can cause corrosion in the shredder.

Explosion Suppression System: Explosion suppression systems are reportedly effective for gas and dust explosions. These systems operate on the premise that there is a delayed (measured in milliseconds) between ignition and the build up of destructive pressure. If a suitable extinguishing agent is injected quickly enough after ignition, the explosion can be prevented.

Several different types of explosion detection devices, including ultraviolet, infrared, thermal and pressure, can be used to activate the suppresion system. In practice, these detection devices activate extinguishing agents (which are stored in pressurized containers) through explosive discharge.

Explosion suppression system extinguishing agents most commonly used in the United States are the halogenated hydrocarbons (halons). Chemical extinguishing powders such as ammonium phosphate and sodium bicarbonate are favored in Germany.

Although experience with explosion suppression has been limited at MSW plants, the number of damaging explosions in automobile fragmentizers has reportedly been reduced considerable after installing and properly maintaining suppression systems.

Explosion suppression systems have reportedly been installed at several MSW installaions, including the following:

Baltimore (City), Maryland

Baltimore County, Maryland

Elmira, New York

Milwaukee, Wisconsin

East Chicago, Illinois

City of Hempstead, New York

Experience: The Factory Mutual Research Corporation (FRMC) of Norwood Massachusetts, published the results of a survey they conducted to assess refuse shredder explosion hazard.[215]

Data acquired in the survey were from MSW processing plants where refuse was shredded for fuel preparation, materials recovery, incineration, or landfill. Included in the survey were the three most common types of refuse shredders; horizontal-shaft hammermills, vertical hammermills and grinders.

The FMRC survey revealed that refuse shredder explosions are a widespread problem at municipal solid waste shredding plants--of the 45 MSW shredding plants included in the survey, 34 (or 76 percent) have experienced at least one explosion. A total of 97 explosions were documented in which some damage occurred, or which required special explosion protection measures to avoid damage. One plant experienced 14 explosions in a 3-year period.

The conclusions reached by FMRC as a result of their survey include the following:

1. Shredder explosions are numerous, but the damage and injury potential is usually limited, due to the structural integrity of the shredder.

2. Only 3 of the 97 explosions documented resulted in personal injury and those three involved personnel in the immediate vicinity of the shredder.

3. Only five of the reported explosions resulted in more than $25,000 property damage or caused the shredder to be shut down for more than a week. Plant damage was usually to peripheral equipment such as conveyors or ducts, which are not as sturdy as shredders.

4. Of the 41 explosions surveyed where a probable cause could be identified, 30 incidents (73 percent) were caused by common flammable gases or vapors--gasoline, propane, paint, thinner. Commercial or military explosives such as dynamite or gunpowder were responsible for 11 (27 percent) of the explosions. Combustible dust and hybrid dust/gas mixtures were possible sources of some of the other explosions.

5. Protection measures that can reduce the frequency and severity of explosions include: manual screening of incoming refuse; continuous water spray within the shredder (effective against flammable vapor and dust explosions as well as fires); explosion venting, when properly designed; pressure-activated explosion suppression systems using Halon 1011 agent, when pressure transducers are carefully maintained to prevent dirt accumulation; and dry powder extinguishing agent (effective against dust explosions).

6. Explosion venting in most of the existing shredders is inefficient. Vents on shredders are often too small, and too remote from the ignition location or too heavy to relieve overpressure. Vent ducts for venting gas out of the shredder building are often missing or not adequate to prevent recompression of the gases. Some plants have modified their vents after the first explosions in order to improve the venting configurations.

The following summarizes the information collected on fire and explosion experiences and protection provided in the processing areas at waste-to-energy plants.

The Ames, Iowa plant has experiences one shredder explosion and one fire to date. The explosion, caused by shortgun shells, was very small and damage was minimal. The first was started by gasoline; again damage was not appreciable. A water spray system and venting are the two preventive measures installed.

Since staring operation, the Baltimore, Maryland, plant has experiences one shredder explosion, one conveyor fire, and one fire in the storage bin. The shredder explosion appeared to be a detonation type of explosion and could have been caused by dynamite. No one was hurt, but a day's work was lost due to repairs needed on the ducts and housing. The conveyor fire was quenched by the sprinkler system and there was no damage. The storage bin fire started spontaneously and the fire department was called to extinguish the fire.

The following protection methods and equipment are employed at the Baltimore City plant, according to information furnished by the designer. There is a sprinkler system in the receiving building and sprinkler systems for all conveyors. A "dry" system is used--water lines are dry to prevent freezing in winter. Should a fire occur, sensors would activate springlers to immediately flood the entire system with water. Each of the two shredders are housed in individual buildings so that an explosion in one shredder will not effect the other shredder. Personnel are not allowed in these buildings when the shredders are operating. Both shredders have explosion supppression systems and relief ducts. The roof is vented to help eliminate dust.

The Eco-Fuel® II produced at the East Bridgewater, Massachusetts, plant holds the potential for explosion problems due to its fine dust-like character. However, specific data on explosions at this plant are not available.

East Bridgewater has a completely sprinkled building (water). Much of the equipment has explosion relief doors. There is a dust control system with pick up points on all the major equipment that generate dust, and there is also a vacuum cleaning system for maintenance. The filters are located outside the building, and the equipment and filter bags are grounded to control build-up of static electricity.

The designer advised that the 1,000 horsepower shredder at the El Cajon plant will not have an explosionsuppression system due to the high cost. There will be an opportunity to segregate such things as oxygen bottles and gasoline cans prior to shredding.

The shredder has an explosion relief in the top of the shredder housing and the feed housing. Just above the shredder housing is an explosion panel through the roof of the building.

Normal fire protection, including hose reels, is provided for the smoldering type of fire. Due to the speed of the conveyor, the operator would not have time to extinguish a fire on the conveyor. The material moves rapidly and is deposited onto the storage pile before the operator could use water to quell the fire while it is on the conveyor. In this instance, should the material start to smolder in the storage pile, the storage pile would by sprayed with a fire hose.

Emergency water sprays operated automatically by temperature control, are provided in the dryer and in the cyclone that collects the dried organic material. Explosion relief is provided in the cyclone duct work in the event of a dust explosion.

The building construction complies with the National Fire Underwriters Building Code.

At the Palmer Township plant, there is a large explosion relief chamber in the primary shredder, according to the designer. A deluge sprinkler system in the shredder is a National Board of Fire Underwriters system that has been adapted for this use. There are two ways to activate it--manually from the control booth or by a temperature-activated device within the shredder.

The building has a sprinkler system. Dust is not a problem, according to the designer, since this is a "closed system." A pneumatic system is used to move the material after it leaves the primary shredder. The system is totally enclosed, with the air being recirculated, so no air will be exhausted.

As discussed in the systems section, the shredder facility at Pompano Beach, Florida, has been in operation for several years. This facility will be used in the methane conversion system. Therefore, the explosion and two fires experienced at the facility are of interest. The shredder explosion caused little damage to the shredder (the shredder is vented), but caused the destruction of 30.5 meters of conveyor. The fire was quenched with portable fire extinguishers. The cause of the explosion was determined to be some paint thinner cans. Small munitions have reportedly gone through the shredder with no effect.

Two conveyor fires were caused by (1) sparks from welding equipment and (2) the motor overheating. The sprinker system was not effective in extinquishing these fires; a regular waterhose has been installed to correct this problem.[215]

The St. Louis, Missouri, plant had a shredder explosion and several fires. The explosion was at the shredder feeder; the cause was not determined. The only damage was that the windows of the control room were shattered. Four fires included: (1) an overheated electric motor which caused extensive damage due to a mistakenly closed sprinkler valve, (2) an air classifier fan, (3) a conveyor belt fire, and (4) a fire in the metal rejects chute from the shredder. The last three fires caused little damage, but had to be quenched with hand fire extinguishers because the fires were too small to trigger the sprinkler system.[215]

ECONOMICS

The data for the study of the economics of processing equipment for waste-to-energy systems were collected by methods similar to those used for the preceding state-of-the-art discussions. First, a literature search was conducted of all available reports and documents dealing with waste-to-energy systems. This search was followed by contacts with equipment manufacturers, personnel at the processing facilities and system designers.

The literature search provided little, if any, meaningful information for comparative economic evaluation. The accounting practices and reporting categories varied widely, making it nearly impossible to assemble costs for comparison purposes. Moreover, the cost information that was presented was in terms of overall systems costs, rather than individual equipment costs. For example, the total size of the crew needed to operate a particular facility was frequently given, but with no indication as to the percent of the crew's time devoted to an individual piece of equipment.

The cost data presented for many of the systems were often preliminary engineering estimates, leading to questions of the validity of the data and the resultant comparative analyses. The weaknesses of these preliminary estimates are exemplified by two cases. The first of these is the scale of the facility. Frequently, the costs, for example, of a 45.4 metric tons per day demonstration plant are merely extrapolated forward for a 1,818.2 metric tons per day commercial plant. Clearly, this sort of estimation procedure is inadequate in an area where economies of scale are undeveloped, and the econo-mics as a whole have not been investigated. Similarly, many of the existing facilities, although full-scale operations, are operating considerably below capacity. The result is that the fixed elements of the cost are distributed over a smaller amount of municipal solid waste, distorting the true economic picture.

The responses by manufacturers to questions concerning economics further expressed the lack of good economic data on MSW processing equipment. In general, the information obtained from manufacturers was limited to capital costs, equipment, all major operating and maintenance costs, quality of the product, and the relationships to other equipment in the system. All of these variables relate to total overall cost of the system, but the relationship is particularly significant for the latter two--quality of output and relationship to other equipment. Two examples of this relationship are: does shredding of MSW to a relatively small size significantly reduce the operation time and wear on other equipment, thus lowering the total operating cost of the system? (2) will the addition of pretrommeling reduce the total cost of the system.[212]

The need to develop reliable information for all of these economic variables is basic for any type of meaningful comparison or evaluations of equipment. Likewise, knowledge of the trade-offs between technical performance and cost of the various equipment is an essential input in the development of a waste-to-energy system. These needs were echoed by virtually all of the manufacturers and designers contacted in this phase of the study, indicating that the state of the art of economics relating to MSW processing equipment is presently properly developed.

SECTION 4

RESEARCH NEEDS

INTRODUCTION

The preceeding section on the state of the art of waste-to-energy processing has not only described the developments in the industry to date, but has also pointed out, both directly and indirectly, those areas where further research is needed. The deliniation of those needs, based upon an understanding of the state of the art, has been a significant focus of this study.

Each of the research needs presented is discussed in the following format: (1) a background review, which summarizes the state of the art relevant to the specific item; (2) a statement of the objective(s) to be met in addressing the research need; and (3) a suggested approach or approaches to address the research need.

In developing this section of the report, no attempt has been made to establish priorities for addressing the research needs, and the order of presentation is not intended to suggest relative importance. The needs are categorized for ease of reference, into: (1) general research needs; (2) research needs relative to particular types of equipment; (3) fire and explosion protection and (4) economic research needs. A listing of specific needs by these categories is presented in Table 14.

Some of these research needs have been undertaken in Phase II of this contract and other EPA sponsored contracts, as noted. However, many of these research needs remain.

TABLE 14. LIST OF RESEARCH NEEDS, BY CATEGORY

General

1. Determine Optimal Arrangements(s) of Unit Processing Equipment.
2. Study Emissions from Processing Equipment.
3. Determine Pertinent MSW Characteristics.
4. Evaluate Potentially Applicable Equipment.

Shredders

5. Compare the Performance of Various Types of Shredders.
6. Determine Maintenance Requirements of MSW Shredders.
7. Determine Optimal Hammer Design(s) for MSW Hammermills.
8. Establish Shred Size Requirements.
9. Evaluate the Cost Effectiveness of Signle Versus Multiple Shredders.

Magnetic Separators

10. Compare Performance of Blet and Drum Magnets.

Air Classifiers

11. Determine the Optimal Operating Conditions for Air Classifiers.
12. Compare the Performance of Difference Types of Air Classifiers.

Screens

13. Compare the Performance of Coarse Screens.
14. Compare the Performance of Fine Screens.
15. Determine the Effects of Pretrommeling.

Dryers

16. Determine the Effect of Drying on Bacteria and Virus.
17. Evaluate the Effect of Drying on Efficiency of Air Classification.
18. Evaluate the Effect of Drying on the Storability of RDF.
19. Evaluate the Effect of Drying on the Combusion Characteristics of RDF.

Densifiers

20. Determine the Optimal Operating Conditions for Densifiers.
21. Determine the Specifications for Densified RDF.

TABLE 14, (continued)

Conveyors

22. Determine the Optimal Operating Conditions for Vibrating and Pneumatic Conveyors.
23. Compare the Performance of Conveyors.
24. Compare the Air Transport Systems.

Storage and Retrieval

25. Compare the Performance of Various Storage and Retrieval Systems.

Receiving Facilities

26. Evaluate Receiving Facilities.
27. Evaluate MSW Segregation Prior to Processing.

Controls

28. Characterize Present Control Systems
29. Determine the Effectiveness of Present Control Systems.

Fire Explosion and Protection

30. Study the Incidence of Fires in MSW Processing Plants.
31. Determine Fire Resistance Characteristics of MSW Processing Equipment.
32. Determine the Effectiveness of Fire Protection Systems in MSW Plants.
33. Study the Incidence of Explosions in MSW Plants.
34. Determine the Effectiveness of Explosion Protection Systems in MSW Plants.
35. Evaluate Spillage and Dust Controls.

Economics

36. Develop Effective Accounting Method(s).
37. Establish Capital Costs of Processing Equipment.
38. Determine Economic Life of Processing Equipment.
39. Determine Equipment Operating and Maintenance Costs.
40. Perform Cost Effectiveness Analysis/

GENERAL RESEARCH NEEDS

Research Need No. 1 - Determine Optimal Arrangement (s) of Unit Processing Equipment

Background

There is considerable variation in the arrangement of the unit processing equipment (shredders, magnetic separators, air classifiers, etc.) in the present and planned waste-to-energy processing systems. To some extent the individual unit equipment and its arrangement depend on the particular fuel or fuel feedstock product being produced. However, even where the same product is produced, there are presently variations in the processing equipment and its arrangement. For example, both the Ames, Iowa, plant and the Chicago, Illinois, plant produce the same product--RDF for use as supplementary fuel. Although both systems start with a primary shredder, from there on the sequence of operations is different. In the Ames plant the sequence of operations after primary shredding are magnetic separation, secondary shredding, and air classification, whereas in the Chicago plant, the operations after primary shredding are air classification and secondary shredding. Even greater differences in the arrangement of unit equipment exist in the various plants preparing fuel feedstocks. It is apparent that a study of optimal arrangement(s) of unit processing equipment is required.

Objective

The purpose of this research is to determine the effect of various arangement(s) of unit processing equipment for producing refuse-derived fuels or feedstocks.

Approach

The first step is to determine the rationale used by the system designers to establish the present unit equipment arrangements at the various facilities. Preliminary discussions with representative system designers indicate that in most cases there were good reasons for the selections and arrangements. However, in some cases,the selection was based primarily on the fact that similar equipment in similar arrangement was used at another plant(s). Even where individual reasoning had been used; in most cases the proof of these judgements has yet to be established on the basis of actual plant performance and cost data are required. Field test data should be collected on different systems which are producing the same product, such as RDF. The data should include: (1) the amount of product produced versus the amount of MSW processed; (2) the quality of the product, including the shred size distribution, the amount of nonburnables, the heat content, and the moisture content; (3) the total energy consumed by the system; and (4) production costs.

Research Need No. 2 - Study Emissions from MSW Processing Equipment*

Background

There is a lack of data on the emissions from MSW processing plants. The only reported data on waste-to-energy processing plants are some tests conducted at the St. Louis demonstraction plant. These tests showed that there was a significant amount of particulate emissions from the air classifier discharge, and there were comparatively high noise levels in the plant (Shannon, et al., May 1975). Additional tests were conduted at the St. Louis Plant to determine the amount and types of bacteria and virus in the air emissions from the plant. Tests conducted on a MSW compost plant showed "extremely high and potentially dangerous concentrations" of particulates emitted from the shredding operation (Ruf, 1974).

It is apparent that additional waste processing equipment tests are required. Also the microorganism content of waste-derived fuels and fuel feedstocks should be investigated to determine whether special handling of these products is required.

Objective

The objective of this research is to collect and analyze the emissions from waste processing plants. An allied objective is to investigate the microorganism content of refuse-derived fuels and feedstocks.

Approach

Tests should be conducted at representative waste processing plants to collect data necessary to evaluate the effluents (air, water, solid, and noise) from these plants. The program should include: (1) a study of emissions from unit equipment; (2) evaluation of the influence of operating parameters on emissions; (3) evaluation of emission control techniques; (4) a thorough analysis of the environmental impacts of waste-to-energy plants. The effluents should be analyzed for composition; trace elements; particulate loading and size; bacteria and virus content; BOD, COD, ph, and leachates. In addition, samples of the MSW stream should be taken throughout the systems and analyzed for potentially hazardous materials including bacteria and virus.

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* This research need has been partially fulfilled under EPA Contract Nos. 68-02-2166 and 68-13-2387.

Research Need No. 3 - Determine Pertinent MSW Characteristics

Background

To properly select and operate equipment to process MSW into a fuel or feedstock, it is necessary to know the characteristics of the MSW. Although some studies of the composition of MSW have been made, a number of characteristics which are important to processing are not known.

Some of the characteristics of the waste which are important from the standpoint of processing equipment are bulk density, composition, moisture content, size distribution, flow characteristics, component densities, abrasives, mircoorganisms, compaction, and storage characteristics.

Objective

The purpose of this research is to determine the characteristics of MSW which are important from the standpoint of processing equipment.

Approach

First, a complete list of the characteristics of MSW that are important from a processing standpoint should be formulated. Then representative samples of MSW should be taken throughout the entire process stream, before and after each process, and analyzed for each characteristic. Data should be taken at various locations around the country, and over the four seasons of the year. A sufficient number of samples should be taken so that the results are statistically reliable.

Research Need No. 4 - Evaluate Potentially Applicable Processing Equipment

Background

There is a tendency in any industry, including the comparatively new resource recovery industry, to use the same or similar equipment used in a previous plant(s). It is natural and logical in designing a new plant to specify a piece of equipment that has been used successfully in a previous plant. However, this tends to minimize the use of new equipment or equipment not previously used in the industry, which may be superior to those normally used.

A considerable amount of equipment has not yet been evaluated for waste-to-energy systems. For example, the 1976 Thomas Register lists 115 manufactures of shredders, 403 manufactures of belt conveyors, 99 manufactures of flight conveyors, and 117 manufactures of pneumatic conveyors. Relatively, only a small number of potentially applicable equipment has been evaluated for waste-processing systems to date. Furthermore, new equipment, such as the knife shredder and discs screens, have been developed which should be evaluated for MSW applications.

Objective

To evaluate processing equipment which may be applicable to resource recovery systems, which have not yet been evaluated.

Approach

The first step in this research should be to survey equipment which may be applicable to waste-to-energy systems and which has not yet been evaluated. A list of the most promising equipment should then be formulated and arrangements made to test this equipment.

New equipment should first be tested in an MSW test facility. Facilities to test MSW processing equipment exist in Washington, D.C. (NCRR), Berkeley, California (University of California), and Toronto, Canada. If the initial tests are promising the equipment should be evaluated in appropriate full-scale resource recovery systems.

Research Need No. 5 - Compare Performance of Various Types of Shredders

Background

A variety of shredders are being used in waste processing systems, including horizontal and vertical shaft hammermills, flail mills, ball mills, ring grinders, and disc grinders. In many cases, different types of shredders are being used for the same purpose. It is not clear whether one type is superior to another for processing MSW. The advantage, disadvantages and limitations of each type of shredder have not yet been firmly established. In-plant operational data are required which will show the performance characteristics of each type of shredder operating under similar conditions, so that shredder selection can be based on direct comparisons.

Objective

To provide comparative performance data on various types of shredders.

Approach

The types of shredders to be investigated should include horizontal hammermills, vertical hammermills, flail mills, ball mills, ring grinders, and disc grinders. The shredders should be evaluated for both primary and/or secondary shredding of MSW. The operating conditions should be as similar as possible so that the results can be compared. The data to be collected should include: (1) amount of energy required per ton of waste shredded; (2) production rates; (3) size analysis of the shredded waste; (4) noise levels near the shredder; (5) weat characteristics; (6) capital and operating costs; (7) downtime and reasons for stoppages; (8) fires and explosions; (9) dust and spillage; and (10) ancillary equipment requirements.

The tests should be conducted at full-scale MSW plants operating under normal conditions. The various types of shredders presently installed or planned in waste-to-energy systems are given in Table 6, Section 3. It would be useful to collect data from as many of these and other plants shredding MSW (listed in appendix D1) as possible to provide a significant data base from which firm conclusions can be drawn.

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* This research need is presently being partially fulfilled under EPA Contract No. 68-02-2586.

Research Need No. 6 - Determine Maintenance Requirements of MSW Shredders*

Background

The maintenance of shredders used to process MSW is a serious problem. Experience has shown that the internal parts of hammermills, particularly the hammers, wear rapidly when processing MSW. In many cases the hammers must be retipped every day. Other parts, such as the breaker plates and grates, also are subject to wear. The exact cause(s) of shredder wear has (have) not been fully investigated, although it is known that MSW contains highly abrasive materials such as glass, hard metals and dirt, which adversely affect shredder components.

Retipping the hammers by welding is a common practice. However, the optimum procedures for retipping, including the proper time to retip, the best welding material, manual versus automatic welding, and the optimum time to repace the entire hammer have not been firmly established. Furthermore, the proper procedures for maintenance of other types of MSW shredders have also not been established.

Objective

The objective of this research is to establish the proper maintenance procedure for hammermills and other types of shredders used for MSW.

Approach

The proper maintenance procedures for shredders should be established on the basis of experience in full scale MSW processing plants. The maintenance procedures employed at representative plants should be recorded along with the performance of the equipment. These data should be analyzed to determine the effects of various procedures on shredder performance and costs. In particular, data should be collected on the procedures and materials used in retipping hammermills, replacement of complete hammers, maintenance of other hammermill parts, and the maintenance of other types of shredders.

The various types of shredders presently installed or planned in waste-to-energy systems are given in Table 6, Section 3. It would be useful to collect data from as many of these plants and other plants shredding MSW (Appendix D1) as possible to provide a significant data base upon which firm conclusions can be drawn.

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* This research need is being partially fulfilled under EPA Contract No. 68-03-2589.

Research Need No. 7 - Determine Optimal Hammer Design(s) for MSW Hammermills*

Background

There are a variety of hammer designs used in hammermills. The shape of the hammers can be blunt-edged, sharp-edged, round-edged, multiple-edged, bell-shaped, double-edged or four-edged and other variations. Furthermore, the number and arrangement of the hammers on the rotors can be varied. There is little or no published information on the advantages and/or disadvantages of various hammer designs for shredding MSW. Some small-scale laboratory work has been done, but no full-scale field test data have been reported.

Objective

The objective of this research is to provide field test data showing the effect of various hammer designs on hammermill performance.

Approach

At least one horizontal-shaft hammermill and one vertical-shaft hammermill in a waste processing plant should be equipped with a variety of hammer designs, and the effects of each design on MSW shredder performance should be determined. The hammer designs should include various shapes, numbers of hammers and arrangements of hammers on the rotor. The shredder performance to be determined should include the shred size, throughput capacity, energy requirements, hammer wear, and other pertinent observations.

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* This research need is being partially fulfilled under EPA Contract No. 68-03-2589.

Research Need No. 8 - Establish Shred Size Requirements

Background

One of the most important specifications for an MSW shredder is the required output particle size. The required output particle size is dependent upon the application of the waste-derived fuel or fuel feedstock. At the present time, shred size requirements vary from about 10 centimeters for some pyrolysis reactors down to 0.15 millimeter for "Eco-Fuel." The nominal particle size for suspension firing of RDF is about 2.5 centimeter. However, the optimal shred size for the various applications has not been firmly established. Furthermore, the effects of gradations within the "nominal" particle size are as yet unknown.

Objective

The purpose of this research is to establish the optimum particle sizes for the various applications of waste-derived fuel and fuel feedstock.

Approach

The first task that should be undertaken is to determine what tests have been conducted to date to establish the particle size requirements for the various applications of waste-derived fuels and fuel feedstocks. The major developers and users of the products and otherinterested organizations* should be contacted for this information. After this information is gathered, a test program should be implemented to provide needed data. Tests should be conducted using a controlled variety of particle sizes in each application to establish the optimum particle size(s) for each. The applications should include suspension-fired boilers, front-firec boilers, pyrolysis reactors, methane generators, pellets, briquettes, and other possible applications of waste-derived fuels and fuel feedstock.

Potential tests sites include installations which presently use or plan to use refuse-derived fuel or fuel feedstock. These installations include the Baltimore County, Maryland, plant; the Ames, Iowa, Power Plant; the Commonwealth plant; the Pompano Beach, Florida, methane plant.

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* ASTM is presently studying MSW fuel specifications.

Research Need No. 9 - Evaluate the Cost of Effectiveness of Single Versus Multiple Shredders

Background

The first RDF demonstration plant (St. Louis) used a single shredder to reduce the raw MSW to a nominal 3.8 centimeter shred size. Most of the newer RDF plants are using two shredders to produce approximately the same shred size. The rationale for using multiple shredders is that the amount of wear on each shredder will be decreased, thereby reducing overall operating costs. This has yet to be proven and reported.

Objective

The purpose of this research is to determine the performance and cost-effectiveness of single versus multiple shredders.

Approach

Performance and cost data should be collected at MSW processing plants using single and multiple shredders. Performance data should include shred size, distribution, throughput, wear rates, and energy consumption. The cost data should include amortized capital, operating and maintenance costs. The collected data should be analyzed to determine whether multiple shredders are superior to single shredders, and, if so, under what conditions.

Potential tests sites for single and multiple shredder tests are listed in Table 6 and Appendix D1.

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* This research need is being partially fulfilled under EPA Contract No. 68-03-2589.

MAGNETIC SEPARATOR NEEDS

Research Need No. 10 - Compare Performance of Belt and Drum Magnets*

Background

Two principal types of magnets are being used to separate ferrous metals from MSW: the belt-type magnet and the drum-type magent. There are a variety of designs within each category. Early designs have not worked well because of unique problems encountered with MSW. As a consequence, both belt and drum-type magnets have recently been redesigned specifically for MSW. As yet, there is insufficient field data available to evaluate the performance of these redesigned magnets. Furthermore, the relative advantages and disadvantages of belt magnets and drum magnets for MSW have not been established.

Objective

To evaluate the performance of recently developed magnetic separators and compare the results of belt and drum types.

Approach

Field tests should be conducted on the "hockey stick" type belt magnets and the dual-drum magnets to determine their performance on recovery of ferrous metals from shredded MSW. The tests of both magnet types should be conducted under similar conditions so that the results can be compared. The data to be collected should include: (1) percentage of ferrous metal recoverd based upon the original amount in the shredded MSW: (2) amount of nonferrous metal contained in the ferrous metal fraction (3) amount of energy required to operate the magnet; (4) maintenance required, and (5) costs. Care should be taken to set up and operate the magnetic separators so that optimum recovery from each magnet is achieved. The conditions fround for optimum performance for each magnet should be reported.

MSW plants using belt and drum type magnets are listed in Appendix D-2.

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* This research need has been partially fulfilled under EPA Contract No. 68-03-2387.

AIR CLASSIFIER RESEARCH NEEDS

Research Need No. 11 - Determine the Optimal Operating Conditions for Air Classifiers

Background

Air classifiers are used in waste-to-energy systems to separate the MSW into two fractions: a light fraction, made up principally of combustibles, and a heavy fraction, containing primarily metals and glass. Operating personnel have complained that there is a lack of information concerning optimal operating conditions for air classifier. This can result in unstaisfactory amounts of glass, metal, etc., in the light fraction, and entrapment of combustibles in the heavy fraction.

Objective

The objective is to determine the optimal operating conditions for MSW air classifiers.

Approach

The types of air classifiers that should be researched are: zig-zag, straight, vibrating, rotary, and concentric tube.* The operating parameters to be investigated can be divided into two groups: those parameters common to all types of air classifiers and those parameters which are different for each type. The common parameters are: (1) airflow rate; (2) air velocity; (3) feed rate; (4) MSW characteristics; (5) position of equipment in the process line; and (6) costs. The unique parameters for vibrating classifiers are the storke and revolutions per minute associated with the vibrating motion; for the rotary classifier the unique parameters are the slope and revolution per minute of the rotating drum.

The performance factors to determine optimality for all the types of air classifiers are: (1) energy consumed, (2) emissions, (3) weat, (4) throughput, (5) characteristics of the "light" fraction and the "heavy" fraction, and (6) operating and maintenance costs.

The best conditions for conducting this test are to have a full-scale operation where it is possible to adjust the operating parameters at will. NCRR, in Washington, D. C., is one such facility. Information may also be obtained through tests at the following commerican plants with the corresponding type of air classifiers (in parenthesis): Chicago, Illinois (vibrating), Pompano Beach, Florida (vibrating), Houston, Texas (rotary), Baltimore County, Maryland* (concentric tube), El Cajon, California (zig-zag), Milwaukee, Wisconsin (zig-zag), and Ames, Iowa (straight).

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* Tests of a concentric tube air classifier at the Baltimore County, Maryland RDF plant have been conducted under EPA Contract No. 68-03-2387.

Research Need No. 12 - Compare Different Types of Air Classifiers

Background

There are five major varieties of air classifiers in use or planned to be used in waste-to-energy systems: zig-zag, straight, vibrating, rotary, and concentric. The relative performance of each type has not yet been established. However, several users have been unsatisfied with the performance to date of various types. This has stimulated the design of new air classifiers such as the rotary and concentric-bute types.

Objective

The objective is to compare the performance of various types of air classifiers under the same conditions.

Approach

The types of air classifiers that should be investigated under this research need are: zig-zag, vibrating, straight, rotary, and concentric-tube. The tests should be conducted under "normal" operating conditions, i.e., similar conditions for each type of air classifier, to insure valid comparison.

The data to be collected for performance comparison purposes are: (1) energy consumption, (2) emissions, (3) equipment wear, (4) capacity, (5) MSW output characteristics, and (6) operating and maintenance costs. The final evaluation will be in terms of cost effectiveness (the trade-off between costs and technical performance).

This research should be conducted at commercial plants. The plant should be full-scale, and operated under "normal" conditions. For a list of potential test sites refer to Research Need No. 11.

SCREEN RESEARCH NEEDS

Research Need No. 13 - Compare Coarse Screens

Background

Trommels (rotary) and disc screens are coarse screens. The disc screen is very new, and little data on its performance on MSW have been compiled. The trommel screen has been tested on MSW by NCRR, TVA, Vista Chemical Company and others.

It would be of interest to determine what screen is best suited for what particular job (e.g., pretrommeling, nonferrous recovery). If they are suited to do the same job, it is valuable to determine the comparative cost-effectiveness. Data are not presently available to answer these questions.

Objective

The objective of this research is to compare the performance of coarse screens on MSW.

Approach

The types of corase screens to be research are trommels and disc screens. The tests should be conducted under normal plant operating conditions.

The performance data that should be collected are: (1) energy consumed, (2) the characteristics of the captured fraction and through fraction, (3) the throughput, (4) equipment wear, and (5) operating and maintenance costs. A further delineation of the material characteristics are: size distribution, moisture content, percent glass, percent ferrous metals, percent nonferrous metals, percent wood, and percent paper. Equipment wear can be determined through maintenance costs, and decrease in thickness of the screen. The final evaluation criteria will be cost-effectiveness.

The tests should be conducted at a full-scale, full operational facility under similar conditions. The following sites have the types of screen shown in parenthesis: East Bridgewater, Massachusetts (trommel); Pompano Beach, Florida (trommel; Houston, Texas (trommel; New Orleans, Louisiana (trommel);

and Palmer Township, Pennsylvania (trommel). There are no known installations using or planning to use a disc screen.

Research Need No. 14 - Compare Fine Screens

Background

Generally, vibrating screens are used for fine screening purposes. The two vibrating screens under investigation for use in MSW-to-energy systems for fine screening are reciprocating and gyrating screens. These two actions have specific effects on the separation efficiency of the screen: (1) the motion determines the time the particles are in contact with the screen (retention time), (2) the regularity or irregularity of the motion affects efficiency, and (3) the motion can affect wear.

Presently, gyrating screens are in use at waste-to-energy plants; reciprocating screens toour knowledge, are not. There have been no tests or studies reported that address the question of efficiency, or cost-effectiveness of fine screening

Objective

The objective of this research is to compare the performance of fine screens.

Approach

The approach to be used is conducting this research is identical to the approach given in Research Need No. 13.

The research should be conducted at a full-scale plant under normal plant operating conditions. Gyrating screens are used at El Cajon, California, and East Bridgewater, Massachusetts. There are no known MSW-to-energy facilities presently using reciprocating screens.

Research Need No. 15 - Determine the Effects of Pretrommeling

Pretrommeling for MSW processing plants has attracted interest due to the following anticipated effects: (1) less wear on the shredders, (2) improved separation in air classifiers, (3) improved form of recoverables for the purpose of selling to secondary markets, and (4) decrease in overall system cost.

There have been some tests conducted to assess some of the operating characteristics of rotary screens.* However, sufficient data to support the use of pretrommeling for waste-to-energy systems have not yet been established.

Objective

To quantitively determine the effects of pretrommeling on waste-to-energy systems.

Approach

The research should be conducted using a trommel under predetermined optimal operating conditions. A minimum process line consisting of a trommel, shredder, and air classifier with the necessary ancillary equipment is needed. The following data should be obtained: (1) capital costs for the trommel, shredder, and air classifier; (2) the amount of wear on the shredder and associated operating and maintenance costs without pretrommeling; (3) efficiency of the air classifier and associated operating and maintenance costs without pretrommeling; (4) the characteristics of recoverables from the "heavy" fraction of the air classifier without pretrommeling; (5) the amount of wear on the shredder and operating and maintenance costs with pretrommeling; (6) the efficiency of the air classifier and operating and maintenance costs with pretrommeling; and (7) the characteristics of the recoverables from the trommel and air classifier.

The wear on the shredder will be indicated by hammer weight loss. The efficiency of the air classifiers will be indicated by the percentage of metals, glass, etc., in the combustible fraction and the percentage of combustibles in the heavy fraction. The characteristics of the recoverables from the trommel and the heavy fraction of the air classifier which should be measured are: percentage composition by weight of glass, ferrous metals, nonferrous metals, paper, plastic, wood, etc.; and the size distribution for each category.

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* Tests of a rotating screen as a pretrommel have recently been conducted by NCRR at the New Orleans, Louisiana, processing plant under an EPA contract.

DRYER RESEARCH NEEDS

Research Need No. 16 - Evaluate the Effect of Dryers on the Efficiency of Air Classification

Background

Some plant operators, and RDF users are not satisfied with the separation efficiency of air classifiers. In particular, they find unacceptable amounts of metals, glass, etc., in the light fraction. Some of the causes of poor air classification performance may be associated with high moisture content of MSW. The removal or reduction of this moisture through a drying system may improve the air classification process. However, data are not available to support this contention.

Objective

The objective is to determine whether the use of a dryer will improve the separation efficiency of MSW air classifiers.

Approach

Tests should be conducted on two process lines with the following minimal equipment; one with a shredder, dryer and air classifier and the other with a shredder and air classifier. The two lines should be identical except for the addition of a dryer in one process line.

The data that should be collected are (1) the amount of noncombustibles in the light fraction, and the amount of combustibles in the heavy fraction for the stream without a dryer, and (2) determination of the same information for the process line with the dryer. This research can be extended to determine the relationship of the heat in the dryer to the moisture reduction and the efficiency of the air classifier.

The trade-offs between improved product quality and the increased costs associated with using a dryer should be taken into account in the final evaluation.

Research Need No. 17 - Evaluate the Effect of Drying on the Combustion Characteristics of RDF

Background

The moisture content of MSW reduces the effectiveness of RDF as a fuel, absorbing energy in the combustion process. It has been shown that the moisture in MSW can be significantly reduced, or eliminated, by installing a dryer in the process line. However, there are presently no data available to show the effect of moisture reduction on the combustion characteristics of RDF.

Objective

The objective of this research is to determine the relationship between drying and the combustion characteristics of RDF.

Approach

The research should be conducted under normal operating conditions using a process line without a dryer and a system with a dryer (all other parameters being equal). The data that should be collected are: (1) the percent of moisture in the RDF, (2) the energy value of the RDF, and (3) the energy consumed by the dryer. The operating parameters of the dryer should be changed to determine their effect on the above data.

Research Need No. 18 - Evaluate the Effect of Drying on the Storability of RDF

Background

There are concerns about the storability of RDF. There are indications that stored RDF presents a fire hazard, is odorous, and has poor flow characteristics. These factors reduce the amount of time RDF can be stored. The storage problem of RDF may be caused, at least in part, by the moisture of MSW.

Theoretically, the removal of the mositure from the MSW should improve or eliminate some of the storage problems of RDF. However, data are not presently available to support this theory.

Objective

The objective of this research is to determine if drying MSW has any positive effects on the storability of RDF.

Approach

This research should be conducted under normal operating conditions using a minimum process line of a shredder, dryer and a long-term storage and retrieval system. The RDF should be stored for various time periods. The following data should be determined, first without a dryer and then with a dryer: (1) percent of moisture in the RDF, (2) amount and type of gases in the storage bin, (3) the temperature of the RDF in the storage bin, and (4) the flowability of the MSW.

Research Need No. 19 - Determine the Effect of Dryers on Bacteria and Virus

Background

Preliminary tests indicate that there may be significant amounts of particulates in the emissions from equipment processing MSW. Additional research on the bacteria and virus in these emissions is being conducted.

Although there is presently no data to substantiate the relationship between the bacteria and virus population and the use of a dryer, equipment manufacturers believe that including a dryer in the system could eliminate all or part of the bacteria/virus from the product and the emissions.

Objective

The objective is to determine whether bacteria and virus in MSW are reduced by passing the waste through a dryer.

Approach

A rotary drum dryer, the only type presently in use at waste-to-energy systems, should be tested under normal operating conditions. The following data should be collected: (1) the bacteria and virus types and counts in the MSW stream and emissions prior to drying; and (2) the bacteria and virus types and counts in the MSW and emissions after drying.

The study can be extended to test the effect of temperature changes on data Item (2). Associated energy consumption, operating costs and maintenance costs should be evaluated.

DENSIFIER RESEARCH NEEDS

Research Need No. 20 - Determine the Optimal Operating Conditions for Densifiers

Background

The two types of densifiers presently of greatest interest for waste-to-energy systems are pellet mills and briquetters. There is interest in densifying RDF because it may: (1) increase storability, (2) enhance transportability, and (3) increase adaptability for certain applications.

Insufficient data on optimum operating conditions for MSW densifiers are presently available.*

Objective

To determine the optimal operating conditions for pellet mills and briquetters.

Approach

The operating parameters should, be varied to determine their effect on the performance of the densifier(s). The operating parameters are identical for both pelltiziers and briquetters: (1) the flow rate, (2) the size distribution of the particles, (3) use or nonuse of a binder; and (4) the composition of the MSW (percent paper, plastic, wood, and moisture).

The optimal operating conditions can be determined by changing the above parameters and observing the resulting effects on the following performance factors: (1) energy consumption, (2) capacity, (3) operating and maintenance costs, (4) the size and shape of the product, (5) the density of the product, and (6) equipment wear.

A pellet mill has been installed at NCRR, Washington, D.C., and Baltimore County, Maryland. Briquetters have not been installed nor are they presently planned for installation at any known facility. It is possible that this research can be conducted at equipment manufacturing sites.

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* NCRR and Teledyne National recently conducted research on pellet mills at the Washington, D.C., and the Baltimore County waste processing plants, respectively.

Research Need No. 21 - Determine the Specifications for Densified RDF

Background

Due to the increasing national interest in using coal burning-boilers, one of the chief advantages to densifying RDF is to adapt it for use in such boilers. Fuel in varying sizes and densities is necessary for effective firing of various types of boilers (e.g., stoker-fired boilers). Presently, there is no information available on the best sizes and densities for densified RDF for such applications.

Objective

To determine the specifications for densified RDF.

Approach

Pellets and briquettes of varying sizes and densities should be produced; the heating value of each should be determined through calorimetric (ASTM standard) laboratory tests; then, the densified RDF should be tested in the boilers. The data should be evaluated, for the purpose of find the best size and density of densified RDF.

CONVEYOR RESEARCH NEEDS

Research Need No. 22 - Determine the Optimal Operating Conditions for Vibrating and Pneumatic Conveyors

Background

There has been extensive research conducted by designers and manufacturers on the best operating conditions for belt and flight conveyors. However, research has not been found which shows the best operating conditions for vibrating or pneumatic conveyors for MSW. Users have encountered wear and plugging problems with penumatic conveyors, and designers have had problems with correct sizing of vibrating conveyors. Therefore, data on the optimal operating conditions of these two types of conveyors of MSW are needed.

Objective

To determine the optimal operating conditions of vibrating and pneumatic conveyors for transporting MSW products.

Approach

The conveyors should be tested under various operating conditions; determination of optimal conditions should then be made by comparing the operating parameters with the resultant performance.

The following are some operating parameters for vibrating conveyors: (1) pan width, (2) angle of incline, (3) stroke, (4) angle of the stroke, (5) cycles per minute, and (6) the MSW characteristics (e.g., particle size distribution, composition, and moisture content). The operating parameters for pneumatic conveyors are: (1) airflow rate, (2) air velocity, (3) pressure, (4) the pipe diameter, (5) the number of bends, (6) the angle(s) of the conveyor, and (7) the MSW characteristics.

The performance factors which should be used to determine optimum operating conditions for both types of conveyors are: (1) energy consumption, (2) throughput, (3) leakage or spillage, (4) wear, and (5) operating and maintenance costs. The following additional factors should be used for pneumatic conveyors: (1) the resultant moisture content of MSW, and (2) the amount of pluggage.

The research should be conducted at full-scale facilities. The following facilities have pneumatic conveyors: Ames, Iowa; and Chicago, Illinois. Vibrating conveyors are in use at Ames, Iowa.

Research Need No. 23 - Compare the Performance of Conveyors

Background

Both belt and flight conveyors are used to transport raw or shredded MSW in waste-to-energy systems. Users cannot agree on the advantages of disadvantages of each type of conveyor. Data are needed to determine the advantages of each type of conveyor for specific MSW transport tasks.

Objective

To compare the performance of belt conveyors and flight conveyors for MSW.

Approach

Test should be conducted under normal operating conditions. It is necessary to maintain identical operating parameters (e.g., MSW characteristics) for both conveyors. The performance data that should be collected are: (1) energy consumed, (2) throughput, (3) operating and maintenance costs, (4) wear, (5) spillage from the conveyors, (6) potential damage due to fire, and (7) damage due to impacts. The final evaluation should be a cost-effectiveness analysis for each conveyor type.

The test site(s) should be a full-scale plant operating under normal conditions. The operating parameters must be similar if multiple sites are selected. The following sites use belt conveyors: Baltimore County, Maryland, South Charleston, West Virginia; Chicago, Illinois; and El Cajon, California. Flight (apron) conveyors are used at Ames, Iowa, Baltimore, Maryland; Baltimore County Maryland; Chicago, Illinois; El Cajon, California and Milwaukee, Wisconsin.

Research Need No. 24 - Compare Pneumatic Transport Systems

Background

There are two types of pneumatic transport systems: negative pressure and positive pressure. Negative pressure systems are generally considered better when transporting material from several locations to one, and positive air systems are considered better for accomplishing the transfer of material from one location to several.

Pneumatic conveyors for MSW have encountered some problems, such as pluggage, leakage and wear. Presently, there are no data available to show which type of air transport system is most effective for transporting MSW.

Objective

To study and compare the performance of negative air and positive pressure transport systems for MSW.

Approach

The tests should be conducted under predetermined optimal operating conditions. The data that should be collected are: (1) amount of leakage or spillage, (2) amount of pluggage, (3) drying effect, (4) energy consumption, (5) capacity of the system, (6) wear, and (7) the operating and maintenance costs. The data should be evaluated in terms of cost-effectiveness.

STORAGE AND RETRIEVAL RESEARCH NEEDS

Research Need No. 25 - Compare the Performance of Storage and Retrieval Systems

Background

There are a variety of storage and retrieval systems available for waste-to-energy plants. Presently, data are not available to compare the performance of the various storage and retrieval systems.

Storage and retrieval system users have encountered several problem areas: (1) nonuniform discharge, (2) bridging and "deadspots", (3) minimal amount of useful storage area, (4) excessive energy consumption, and (5) minimum storage time due to odor, fire hazards, and packing.

Objective

To compare the performance of different storage and retrieval systems for RDF.

Approach

The storage and retrieval systems that should be evaluated are: (1) a conical bin with sweep bucket retrieval, (2) an inverted bin with screw discharge, (3) an inverted bin with roller discharge, (4) a rectangular bin with doffing rolls and screws, and (5) a bin with vertical and horizontal screw discharge.

The following data should be collected: (1) the controllability and uniformity of discharge; (2) the amount of bridging; (3) the occurrence of "dead spots;" (4) storage bin feed-in rate; (5) the ratio of useful storage area to the area of the entire bin; (6) the energy consumed; (7) the operating, maintenance, and capital costs; and (8) the concentration of gases within the bin.

The following is a list of waste processing facilities with their corresponding types of storage and retrieval systems: Ames, Iowa (conical, with sweep buckets); Baltimore, Maryland (conical with sweep bucket); Chicago, Illinois (conical, with sweep buckets); El Cajon, California (rectangular, with doffing rolls) and St. Louis, Missouri (inverted, with screws).

RECEIVING FACILITIES RESEARCH NEEDS

Research Need No. 26 - Evaluate Receiving Facilities

Background

Receiving facilities play an important role in waste processing plants, yet little has been reported on the performance of these facilities. The principal functions of receiving facilities are to: (1) weigh the incoming MSW delivery trucks, (2) provide facilities to receive and temporarily store the MSW, (3) remove undesirable material from the MSW, and (4) feed the MSW into the processing system. There are various designs and layouts of receiving facilities being used; the scales may be outdoors or indoors; the truck weights may be recorded manually or automatically; the truck traffic patterns are different; the loads may be dumped on the floor or into pits; techniques for removal of undesirables vary; and the method for moving the MSW from the storage area to the feed conveyor may be by pusher trucks or hydraulic rams. In spite of their importance and the significant variations in design, there has been no reported systematic evaluation of MSW receiving facilities.

Objective

The purpose of this research is to evaluate the performance of receiving facilities in waste processing plants. The various types of receiving facilities being used should be evaluated and the results compared.

Approach

The evaluation of receiving facilities should include: (1) the time required for the delivery trucks to be weighed, dump their loads, and depart from the plant; (2) the number of trucks that can be accommodated per shift; (3) difficulties experienced by the truck drivers within the plant; (4) the accuracy of the weighing process; (5) the ability to remove undesirable material from the waste pile; (6) the cost effectiveness of total-truck versus single-axle scales; (7) the effectiveness of receiving pads versus pits; (8) the advantages and disadvantages of wheel loaders versus hydraulic ram loaders; (9) environmental pollution within the receiving building; and (10) effects of receiving facility layout on performance and costs.

Research Need No. 27 - Evaluate MSW Segregation Prior to Processing.

Background

There is almost an unlimited variety of objects which may appear in MSW which should be removed prior to processing in a waste-to-energy plant. Bulky objects, such as discarded refrigerators, mattresses, motor blocks and tires, are usually too large or dense to be accommodated by the primary shredder. Some objects are undesirable because they can cause fires or explosions in the shredders. Included in the latter category are commercial and military explosives, and a variety of flammable liquids, gases, and dust.

The problem is how to identify and remove undesirable objects prior to processing. Large, bulky wastes are readily identifiable, and in many (but not all) cities, these are collected and disposed of separately. It is the small, dense, flammable or explosive objects that present a major problem because they cannot be easily identified. Various techniques are being tried to identify and remove these undesirable objects, with only moderate success. Some plants have instructed the trash collectors to avoid putting any suspicious objects in the refuse trucks. However, in most cases it is left to the operators of the front-end loader and the shredder feed belt to visually identify and remove any undesirable objects prior to entry into the primary shredder. The lack of effectiveness of the present procedures is affirmed in a recent survey of MSW shredding plants covering nearly 100 explosions in MSW processing plants. Although it is probably impossible to identify and remove all undesirable objects from MSW, it is desirable to conduct additional research in this area in an attempt to improve the present situation.

Objective

The objective of this research is to develop effective methods that will identify and remove undesirable objects from MSW prior to processing.

Approach

The first step is to study the present techniques for identification and removal of undesirable objects to determine which is most effective. The next step is to conceive and evaluate tehniques which will improve the effectiveness of segregation prior to processing.

EQUIPMENT CONTROL RESEARCH NEEDS

Research Need No. 28 - Characterize Equipment Control Systems in Waste Processing Plants

Background

The controls addressed here refer to the electrical system through which the various pieces of processing equipment are operated and controlled. The electrical control system ties all of the separate pieces of equipment together into a complete processing entity.

Literature searches have revealed very little information regarding electrical control systems at MSW plants. The information obtained from direct contact with plant designers is sketchy and incomplete.

Objective

The objective of this research is to characterize the electrical control systems at present and planned resource recovery plants.

Approach

As a first step, a data form covering resource recovery plant control systems should be designed. The data forms should then be mailed to the designers of each of the MSW systems being studied. Each plant designer would be asked to complete the data form and return it, plus any available wiring and/or block diagrams on the system.

It will probably be necessary, in some cases, to visit plants personally to obtain complete control system data, wiring diagrams, block diagrams, etc. In these instances, photographs should be taken (assuming permission is granted) of the operator's control booth, control console, push button panels, control room and other control panels and equipment.

The completed control system data forms, photographs and wiring and block diagrams will represent a data base from which the characteristics of preprocessing systems at present resource recovery plants can be analyzed and compared.

Research Need No. 29 - Determine the Effectivenss of Equipment Control Systems At Waste Processing Plants

Background

Preliminary discussions with system designers indicate that the electrical control systems are custom-designed for each plant, and vary widely in degree of sophistication from plant to plant. Some designers have taken a minimal approach, relying on simple, manual instrumentation and control, while others favor highly automated control systems.

Objective

The primary objective of this research is to establish the differences in effectiveness of control systems at waste processing plants. The research should attempt to answer the following questions:

1. Under what circumstances does the simple, manually-operated control system seem to be more effective than the more sophisticated, automated control system?

2. Under what set of circumstances is an automated control system, rather than a manual control system, necessary?

3. Compare the simple, manual control to a more automatic control system; what is the difference in number of personnel required to operate the plant?

4. When does a control system become "too automatic"--so complicated that the cost-effectiveness is reduced?

5. From the standpoint of safety, what are the advantages and disadvantages of the various control systems?

6. What are the general guidelines and minimum requirements that need to be satisfied when installing electrical controls for the processing area in resource recovery plants?

Approach

As a first step, the completed control system data forms, photographs, wiring diagrams, block diagrams, etc., obtained in Research Need No. 28, should be analyzed and information compiled for later use. Field surveys would then be run to evaluate the advantages and disadvantages of different types of control systems.

Research Need No. 30 - Study the Incidence of Fires in Waste Processing Plants

Background

The number of fires which have occurred at MSW processing facilities indicates that the fire hazard is significant. A major factor contributing to this hazard is the heterogeneous and combustable nature of mixed municipal waste.

Objective

The objectives of this research are to answer the following questions regarding fires at MSW plants: (1) in what area of the plant have most fires occurred? (2) what were the causes of these fires? (3) what was the amount of damage resulting in each of the fires? (4) what injuries resulted from the fires? (5) what was the downtime resulting from the fires; and (6) how were the fires extinguished?

Approach

A basic method would be to gather detailed data relative to the above questions from MSW plants that have experienced fires. As a first step, a data form for compiling the desired information should be designed. These data forms, after being completed, would make up a basic Fire Experience Data Bank for later interpretation and analysis.

It is anticipated that several methods would be used in gathering the data and completing the data forms including: (1) literature searches; (2) data from system designers and operators, and insurance companies; (3) telephone contacts; and (4) visits to MSW plants.

Research Need No. 31 - Determine Fire Resistance Characteristics of Waste Processing Equipment

Background

Preliminary research has uncovered several instances of fires in municipal solid waste processing plants which were started and/or spread because of the flammability of some of the equipment components. There have been cases of rubber conveyor belts catching fire, and other cases of equipment components starting the fire.

Objective

The purpose of this research would be to determine which of the equipment components in the processing portion of resource recovery plants would be candidates for replacement by fire-resistant components and what other fireproofing techniques should be employed. The research would address the following:

1. Which of the processing equipment and supplementary equipment if flammable; i.e., could start a fire or add to the spread of a fire?

2. Are there fire-resistant materials and/or equipment than can replace identified fire hazards?

3. What other fireproofing procedures would be advantageous?

Approach

As a first task in this study, the "Fire Experience Data Bank" developed in Research Need No. 30 should be analyzed to determine which pieces of equipment or components of MSW systems have been responsible for the fires that have already occurred. The second task would involve on-site inspections of waste processing facilities. Insurance company specialists, personnel with the National Fire Protection Association and other interested organiations may be asked to assist in this task. The last task would entail contracting and obtaining recommendations from various equipment component manufacturers.

Research Need No. 32 - Determine the Effectiveness of Fire Protection Systems in Waste Processing Plants

Background

The research conducted to date indicates that the probability of fire in MSW plants is high. Apparently, most of the fires originate in the shredder area, but there have also been reports of fires in other areas including conveyor lines, control rooms, and storage bins.

Objective

The objective of this research is to study the experience of waste processing plants that have experienced fires to determine which fire protection systems have been effective and which were ineffective in preventing or extinguishing fires.

Approach

The first task would be to analyze the information regarding past fires at MSW plants, utilizing the Fire Experience Data Bank developed in Research Need No. 30, and make additional contacts as necessary. The second task would be to determine which fire protection measures have been effective for: (1) preventing fires, and (2) controlling and/or extinguishing fires after they start.

Research Need No. 33 - Study the Incidence of Explosions in Waste Processing Plants

Background

Waste processing plants are vulnerable to explosions because of the heterogeneous nature of mixed municipal refuse. The explosion hazards include such items as gasoline and solvent containers, propane tanks, ammunition, gunpowder, dynamite, TNT, and occassionally even live ordinance. Combustible dust, flammable gases and hybrid dust/gas mixtures are also possible explosion sources in waste processing plants.

Objective

The purpose of the research is to answer the following questions: (1) in what area of the plant have most explosions occurred? (2) what were the causes of these explosions? (3) what was the amount of damage resulting in each of the explosions? (4) what injuries resulted from the explosions? (5) what was the downtime resulting from the explosions; and (6) what changes or modifications were made to guard against a similar occurrence in the future?

Approach

As a first step, a data form for compiling the desired information should be designed. One data form would be completed for each explosion researched. These data forms, after being completed, would form a basic Explosion Experience Data Bank for later interpretation and analysis.

It is anticipated that several methods would be used to gather the data including: (1) literature searches; (2) mailing data forms, along with an explanatory letter, to system designers and operators and other data sources; (3) telephone contacts; (4) personal visits to MSW processing facilities; and (5) working with insurance companies to develop information from their files.

Research Need No. 34 - Determine the Effectiveness of Explosion Protection Systems in Waste Processing Plants

Background

Municipal solid waste processing plants are vulnerable to explosions because of the heterogeneous nature of mixed municipal refuse. The explosion hazards include such items as gasoline and solvent containers, propane tanks, ammunition, gunpowder, dynamite, TNT, and occassionally even live ordinance. Combustible dust, flammable gases and hybrid dust/gas mixtures are also possible explosion sources. Other industries, such as automobile shredding have gained experience which may also be applicable to processing MSW.

Objective

The objective of this research is to answer the following:

1. What venting configurations, water spray systems, suppression systems, and other preventative measures have proved most successful in other industries?

2. Which of the techniques employed in the automobile scrap and other industries are adaptable to municipal solid waste systems?

3. What modifications in explosion protection systems have been made at MSW shredder installations that have already experienced explosions. Which protection measures have proved effective?

4. What surveillance and screening methods are most effective for eliminating hazardous materials from the refuse fed into the shredder?

5. Can the experiences in Germany with dry powder extinguishing agents help us in MSW explosion problems in the U.S.?

6. What is the incidence of explosive vapor concentration in shredders?

7. How effective is a shredder water spray system for explosion protection?

8. What is the feasibility of an emergency water spray system in shredders that would be activated before ignition, as soon as a high-flammable gas or vapor concentration is detected?

9. What venting configurations for different types of shredders are most effective?

10. Which halon explosion suppression system is most effective for the different types of shredders?

Approach

The research would consist basically of data gathering through the following:

1. Contact with automobile fragmentizer operators, fragmentizer equipment manufacturers, insurance companies, and others. Methods employed in collecting the data would include mailing data forms, telephone contact, and personal visits. Preferably, the researchers should build a file of photographs to supplement the other data.

2. Survey existing refuse shredder operators who have experienced explosions at their plants.

3. Experiment with different techniques, including both manual and automatic, for screening and sorting out hazardous materials before they enter the shredder to determine which techniques are most effective.

4. Investigate the explosion tests that have been conducted in Germany with dry powder extinguishing agents. Field test the effectiveness of these dry agents.

5. Monitor flammable gas concentrations in operating shredders to determine incidence of occurrence.

6. Conduct shredder explosion tests with and without a water spray system.

7. Using the experience and information gained from tests described in 5 and 6 above, design and test the effectiveness of an emergency water spray system that is activated as soon as a high-flammable gas or vapor concentration is detected (before ignition).

8. Conduct shredder explosion tests to learn more about:

- Structural integrity of shredders; and
- Venting configurations that are most effective for different shredders.

9. Test the effectiveness of shredder explosion suppression systems to determine designs that work best for the different types of shredders. The effects of agent concentration and container location should be included in these tests. Also, the effects of dirt accumulation in the pressure transducers

and techniques for eliminating the dirt accumulation problem should be investigated.

Research Need No. 35 - Evaluate Spillage and Dust Controls

Background

Spillage and dust are generated throughout MSW processing plants. Dumping the raw MSW from the delivery trucks, moving the MSW onto the feed conveyor, conveying the MSW, shredding the MSW, air classification and almost every other step in the process cause spillage and dust to be liberated from the waste stream. Uncontrolled spillage and dust are undesirable because of potential health hazards to plant personnel, fire and explosions, and general housekeeping. Some attempts have been made to control spillage and dust in MSW processing plants. Some of the more recent waste-to-energy plants have included dust collection systems, but their effectiveness has not yet been tested. Attempts have been made to minimize spillage by installing enclosures around the processing equipment, but complete control of spillage has yet to be achieved.

Objective

To evaluate present spillage and dust control systems in waste-to-energy plants, and determine which systems are most effective.

Approach

Tests should be conducted in resource recovery plants equipped with the latest techniques for spillage and dust control. The amount of spillage and dust collected throughout the plant should be measured and recorded daily over a period of about 1 week at each plant. The type of control system should be described any any operating problems reocrded. For caomparison, tests should also be conducted in a plant which is not equipped with such controls. Recomendations for possible improvements in either the design or operation of the control systems should be made.

Waste-to-energy plants equipped with spillage and/or dust controls include the Chicago, Illinois, plant; and Baltimore County, Maryland,* plant. A potential test site for a plant not equipped with dust control is the Ames Iowa, plant

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* Preliminary tests of the dust control system at the Baltimore County plant were recently conducted under EPA Contract No. 68-03-2387.

ECONOMIC RESEARCH NEEDS

Research Need No. 36 - Develop Effective Accounting Method(s)

Background

One of the major deficiencies in studies of the economics of MSW processes is the lack of standard accounting practices to facilitate the comparison of economic data. Standardization, however, is not sufficient in itself. The inputs to the accounting system must be easily collected; and the output should be in a form that is useful for the type of analysis that is required.

The need to develop an effective accounting system is apparent in many of the preceding research needs. However, its use is not limited to these areas. Both existing and future waste processing facilities will require the information that can be derived from this system. Existing facilities will need this information to monitor performance, to determine optimal equipment replacement schedules and to evaluate new equipment developments. Future recovery facilities will need the information in the selection of equipment and for determing financial requirements.

Objective

To develop an accounting system for waste processing plants that is consistent, provides useful information, and is easy to maintain.

Approach

The approach that should be taken in developing an effective accounting system is two-fold. First is the formulation of a conceptually valid system. The second, accomplished simultaneously, is an analysis of accounting systems currently being used at the various recovery facilities. This step possibly could be expanded to include other industries with similar characteristics--large capital costs, and relatively undeveloped. Examples of such industries include solar reactors, nuclear power plants, etc.

The evaluation criteria to be used in both steps of this approach are: (1) timeliness of information; (2) usefulness of information; (3) ease of maintenance; and (4) consistency.

Research Need No. 37 - Compare Capital Cost of Processing Equipment

Background

Capital cost is the first variable required in making any type of comparison of various equipment through cost-effectiveness. Moreover, capital cost includes more that just equipment cost. Labor for installation, a major adaptations to plant or equipment required for implementation in a particular system, other installation costs, term of debt instrument (if any), cost of capital, and the cost of the required square footage of the plant are examples of the other types of cost that should be included in capital costs.

Objective

To identify the true capital cost of resource recovery processing equipment.

Approach

The first step in establishing the capital cost of a particular piece of equipment is to identify all segments of the cost. Next, data must be collected on these identified costs. It is necessary to develop a mechanism to collect these data. This mechanism may be taken from the standard accounting system suggested in the preceding research need.

A value analysis should then be performed on each piece of equipment of interest so that realistic comparisons can be made within each class of equipment, such as shredders, air-classifiers, and conveyors.

Research Need No. 38 - Determine Economic Life of Processing Equipment

Background

"Economic life" may be defined as that point in time when replacement of a given piece of equipment becomes more cost-effective than additional repair. The importance of economic life is implicit in any capital budgeting decision. Likewise, working capital requirements are directly tied to the useful life of a piece of equipment as is its cost-effectiveness. Because much of the equipment used in recovery facilities is totally new, and others, such as shredders,have such limited experience on MSW, any attempt to extrapolate economic life from current data would be severely deficient.

Objective

To determine the economic life of processing equipment in resource recovery systems.

Approach

Two different approaches are described accompanied with a brief statement of their advantages and disadvantages.

The first approach utilizes information on economic life and the associated cost curves for a particular piece of equipment as used in other areas. From these data a probable economic life and cost curve can be estimated. There are two major weaknesses with this approach. First, there is no reason to believe, for example, that the way a shredder reacts in the grain industry has any relationship to the way it reacts on MSW. Second, this analysis is limited to only a few equipments, since many have been developed specifically for MSW and, therefore, have no histories from which to draw comparisons.

Another approach to determine economic life is to observe the equipment over a long period of time, perhaps as much as 20 years. During this observation period it will be necessary to collect data on all maintenance costs and their timing. In addition, for any operating costs that increase over the life of the equipment (for reasons other than inflation) data will also have to be collected. From these data (and the capital cost data discussed in Research Need No. 37) a capital budgeting model can be developed to identify the economic life. Although this approach is considerably more accurate than the first approach, there is a problem with the great amount of time that is required.

Research Need No. 39 - Determine Equipment Operating and Maintenance Costs

Background

The operating and maintenance costs are extremely important variables in the economic analysis of MSW processing equipment. Experience at some facilities has shown that these costs fluctuate widely and can mean the difference between financial success and failure. Unfortunately, these costs are presently misunderstood and undeveloped.

Objective

To identify the operating and maintenance costs associated with MSW processing equipment.

Approach

For each class of equipment to be studied, a comprehensive list of operating and maintenance costs should be developed. These costs include labor, energy, other utilities, repairs (including frequency), etc. On-site data collection and detailed analysis will be required.

It is paramount that an effective accounting system, such as described earlier, be used for collection of these data to insure reliability. Careful attention must be paid to detect variations in the costs due to changing parameters, such as the effect of other equipment in the system, throughput, and quality of the product.

Research Need No. 40 - Perform Cost-Effectivensss Analysis

Background

As municipalities and other organizations concerned with the funding of resource recovery facilities become more demanding in terms of justifying expenditures, cost-effectiveness analysis will become increasingly important. It can be used, for example, to investigate the trade-offs between costs and technical performance--a key to identifying optimal systems.

Objective

To perform cost-effectiveness analysis of MSW processing equipment.

Approach

The approach used in this analysis should combine economic data and technical performance data to formulate the following relationships:

$$C_i = f\ (K_i,\ L_i,\ Q,\ O_iM_i,\ E_j)$$

where C_i = cost-effectiveness of equipment type i

K_i = capital cost of equipment i

L_i = economic life of equipment i

E_j = relationship to other equipment j in the system

Q = quality of the product

O_iM_i = operating and maintenance cost of equipment i

APPENDIX A

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APPENDIX A-1

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APPENDIX A-2

MANUFACTURERS' OF WASTE PROCESSING EQUIPMENT

Air Classifiers

Mac Equipment Company
Triple/S Dynamics
Americology
Combustion Power Company
Occidental Research and Development
Rader

Conveyors

Aerodyne Machinery Corporation
American Baler Company
Balemaster
Freeman Balers
Hammermills, Inc.
Mayfran
Peak Conveyors, Inc.
Rexnord
Sullivan Equipment Company
Goodyear (conveyor belts)
Jeffrey Manufacturing Company

Cyclone Separators

Fisher-Klosterman
Carter-Day

Dryers

M. E. C.
[illegible]

Fire/Explosion Control Systems

Fenwal

Magnetic Separators

Dings Magnetic Group
Eriez Magnetics
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Shredders/Pulverizers

American Pulverizer Company
Beloit Jones
Bema Engineering
Demom Manufacturing Company
Detroit Stoker Company
Eidal Metal Processor (mfd. by Carborundum)
Gruendler Crusher and Pulverizer
Hammermills, Inc.
Hazemag
The Heil Company
Jeffrey Manufacturing Company
Frances and John S. Lane Limited
Montgomery Industries International
Newell Manufacturing Company
Pennsylvania Crusher Corporation
Rexnor, Inc.
Saturn Manufacturing, Inc.
Tracor Marksman
Williams Patent Crusher Pulverizer
Enterprise Company

Storage Bins

American Sheet Metal, Inc.
Atlas Systems
Sprout-Waldron
Miller-Hofft

Screens

Rotex Screeners
Rader
Gruendler
Triple/S Dynamics

Filters (Baghouse)

Griffin Environment Company
Carter-Day
[illegible] Equipment Company

Total Systems

Allis-Chalmers
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APPENDIX B

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Don Kaminsky, Manager Heil Company 3000 West Montana Street P. O. Box 593 Milwaukee, Wisconsin 53201	Shredders, Compactors, Dryers
Harry J. Skelton, Vice President Gruendler Crusher and Pulverizer Company 2915 North Market Street St. Louis, Missouri 63105	Shredders, Trommels
John Koszakoski, Marketing Coordinator Ralph French, Engineering Enterprise Company 616 South Santa Fe Santa Anna, California 92705	Shredders
Harold Crowe Williams Patent Crusher and Pulverizer Company 2701-2723 North Broadway St. Louis, Missouri 63102	Shredders, Conveyors
E. M. Schueler Dings Company - Magnetic Group 4740 West Electric Avenue Milwaukee, Wisconsin 53219	Magnetic Separators

CONTACTS (continued)

K. N. Ugargol CEA-Carter-Day 500 - 73rd Avenue N. E. Minneapolis, Minnesota 55432	Dust Collectors, Air Transport
M. Patterson Raytheon Service Company 12 Second Avenue Burlington, Massachusetts	Air Classifiers
L. O. Snyder Mac Equipment, Inc. 6420 Underwood Avenue Omaha, Nebraska 68132	Air Classifiers, Dust Collector
K. R. Sterrett, Principal Engineer Sprout-Waldron Metal Products Division Koppers Company Muncy, Pennsylvania 17756	Storage and Retrieval
Eugene M. A. Baikoff, President Jacques Rossat Bema Engineering Company 4 Chemin de Roseneck Lausanne, Switzerland	Shredders
Murray D. McMahon R. C. DiCenso Westinghouse Electric Corporation 1215 West 12th Street Kansas City, Missouri 64101	Electrical Controls
Mr. Andrew J. Martin Systems Engineer Protection Systems Division Fenwal, Inc. Division of Walter Kidde Company Ashland, Massachusetts	Explosion/Fire Protection

CONTACTS (continued)

Ronald E. House Safety, Inc. St. Louis, Missouri	Explosion/Fire Protection
Pat Ertz Safety, Inc. 2500 South Mill STreet Kansas City, Missouri	Explosion/Fire Protection

APPENDIX C

EQUIPMENT SPECIFICATIONS

Table C-1

EQUIPMENT DATA - SHREDDERS

Manufacturer	Am Pulverizer	Williams	Williams	Williams	Gruendler	Jeffrey
Model	60-90	680	780	6,100	84-60	994
Type	Horizontal Hammermill	Horizontal Hammermill	Horizontal Hammermill	Horizontal Hammermill	Horizontal Hammermill	Horizontal Hammermill
Reversible	No	No	No	Yes	NA	No
Weight (kg)	47,627	44,934	61,364	61,364	43,773	70,455
Voltage (volts)	4,160	NA	NA	NA	NA	NA
Dust Control	Water Spray	NA	Yes	NA	NA	NA
Startup Time						
Empty (seconds)	18	NA	NA	NA	NA	NA
Loaded	NA	NA	NA	NA	NA	NA
Rundown Time (minutes)	15-20	NA	NA	NA	NA	NA
Hammer						
Material	Wearalloy "R"	Manganese	Manganese	Manganese	Hatfield Manganese	NA
Weight (kg)	27.2	71.81	NA	NA	55	NA
Number	48	32	32	60	30	30
Shape	NA	NA	NA	Bell	Double Faced	Hour Glass
Velocity (m/s)	57.6	NA	NA	NA	NA	NA
Replaceable	Yes	Yes	Yes	Yes	Yes	Yes
Tippable	Yes	Yes	Yes	Yes	Yes	Yes
Hammer Coverage of Grate	Full	Full	Full	Full	NA	Full
Breaker Plates						
Material	1040/1050 Carbon Steel	Manganese	Manganese	Manganese	NA	NA
Adjustable	No	Yes	NA	Yes	NA	NA
Reversible	No	Yes	NA	Yes	NA	NA
Grate						
Size (cm)	22.9 x 22.9 (7.6 x 12.7)	NA	NA	NA	7.6	NA
Weight (kg)	952.5 (351.5)	NA	NA	NA	NA	NA
Thickness (cm)	20.3	NA	NA	NA	NA	NA
Adjustable	No	NA	NA	NA	NA	NA
Motor						
HP	1,000	1,000	1,000	1,000	NA	1,000
RPM	780	900	720	900	900	NA
Rotor						
Diameter (m)	1.5	NA	NA	NA	NA	NA
Speed (m/s)	57.6	NA	NA	NA	NA	NA
Inertia (kg-m^2)	198.5	NA	NA	NA	NA	4435.6
Normal Capacity (Mg/hr)	36.3-40.8	NA	NA	NA	NA	NA
Peak Capacity (Mg/hr)	45.4	72.7	NA	72.7	32	23
Capital Cost ($)	NA	NA	NA	NA	NA	NA
Power (kw)	NA	NA	NA	NA	1,026	NA
Energy Consumed (KJ/Mg)	NA	NA	NA	NA	NA	NA

NA = Not available or not applicable.

TABLE C-1 (concluded)

Manufacturer	Carborundum	Beloit	Heil	Heil	Tracor Marksmen	Heil
Model	1,000	Shredmaster	420	--	860	92B
Type	Ring	Disk	Vertical Hammermill	Vertical Hammermill	Horizontal Hammermill	Vertical Hammermill
Reversible	NA	NA	Yes	Yes	Yes	Yes
Weight (kg)	48,182	500	10,000	9545.4	40,909	70136.4
Voltage (volts)	NA	480	460/3	460/3	120/4,160	115/4,160
Dust Control	NA	NA	NA	NA	Baghouse	Mg. Pneumatic Air
Startup Time						
Empty (seconds)	NA	60	5-10	5-10	150	5-10
Loaded (minutes)	NA	NA	NA	NA	5	NA
Rundown Time (minutes)	NA	2	4	4	25	24.25
Hammer						
Material	NA	NA	SAE 1060	HRS	Manganese Steel	HRS
Weight (kg)	29	NA	6.5	Variable	77.3	7.3 and 9.45
Number	60	2	34	NA	24	44
Shape	NA	NA	Rectangular	Thin Rectangular	Pie	Rectangular
Velocity (m/s)	34.5	NA	68.6	68.6	71.95	89.3
Replaceable	NA	NA	Yes	Yes	Yes	Yes
Tippable	NA	NA	Yes	Yes	Yes	Yes
Hammer Coverage of Grate	NA	NA	NA	NA	180°	NA
Breaker Plates						
Material	NA	NA	NA	NA	TRI-50-X	NA
Adjustable	NA	NA	NA	NA	No	NA
Reversible	NA	NA	NA	NA	Yes	NA
Grate						
Size (cm)	NA	NA	NA	NA	15.2 x 15.2	NA
Weight (kg)	NA	NA	NA	NA	NA	NA
Thickness (cm)	NA	NA	NA	NA	20.3	NA
Adjustable	NA	NA	NA	NA	No	NA
Motor						
HP	1,500	250-500	200	250	1,000	1,000
RPM	NA	1,200-1,800	1,775	1,775	800	600
Rotor						
Diameter (m)	1.5	NA	1.1	NA	20.3	NA
Speed (m/s)	9.2	NA	68.6	68.6	71.95	89.3
Inertia (kg-m^2)	5280.5	NA	118.3	118.3	NA	NA
Normal Capacity (Mg/hr)	NA	NA	13.6	NA	54.5	32.7
Peak Capacity (Mg/hr)	72.7	NA	22.7	NA	90.9	38.2
Capital Cost ($)	NA	NA	20,000	20,000	NA	NA
Power (kw)	NA	NA	149	186	540	NA
Energy Consumed (KJ/Mg)	NA	NA	NA	NA	60,346	NA

TABLE C-2

EQUIPMENT DATA - MAGNETIC SEPARATORS

Manufacturer	Sterns	Eriez	Dings	Dings
Model	30-A	SR	60 in. SUMS	48 in. SUMS
Type	Belt	Drum	Belt	Belt
Weight (kg)	2,268	9,979	5,454.5	6,364
Voltage	230/460/3/60	NA	120/575	230/460 3 amps 60 Hz
Separator				
Width (m)	1.4	1.8	1.5	1.2
Speed (m/s)	1.5	NA	79.3	30.5-122
Magnet				
Size (cm)	76 x 86 x 60	59 width	NA	NA
Weight (kg)	1,164	NA	NA	NA
Type	Electromagnet	Permanent and Electromagnet	Electromagnet	Electromagnet
Power (kw)	2.75	7.2	15	14.3
Normal Capacity	24	NA	54.5	NA
Peak (Mg/hr)	45	45	90.9	45
% Fe	95	90-95	95+	95+
Energy Consumed	36.5 KJ/Mg	10 HP	848 KJ/Mg	5 HP
Capital Cost ($)	6,614	22,000	35,000	23,000

Source: Equipment manufacturers.

TABLE C-3

EQUIPMENT DATA - AIR CLASSIFIERS

Manufacturer	Raytheon	Triple/S	Rader	NRRC
Model	1102B	Vibrolutrator	130	2 Classifiers
Type	Rotary Drum	Vibrating	Straight	Concentric
Voltage	230/460	NA	NA	NA
Dimensions				
Length (m)	17.9	NA	7.6	9.1, 4.6
Width (m)	6.9	NA	2.6	2.1, 1.5
Height (m)	12.8	NA	NA	NA
Ancillary Equipment	Airlock Blower Conveyor Dust Collector	Blower Cyclone Separator Airlock	Airlock Blower Conveyor Cyclone Separator	Cyclone Blower Airlock
Airflow (m^3/sec)	NA	9.4	18.9-23.6	NA
Velocity (m/sec)	1.5-4.1	NA	NA	NA
Motor				
HP	6/15,7.5,75, 2,10,150	3/250,30,25	25,200	2/200
RPM	NA	NA	1,750-1,780	NA
Normal Capacity (Mg/hr)	NA	NA	28	NA
Peak Capacity (Mg/hr)	32-36	72.7	45	68.2
Capital Cost ($)	NA	NA	114,934	NA

Source: Equipment Manufacturers.

TABLE C-4

EQUIPMENT DATA - SCREENS

Manufacturer	Rotex	Rader	Triple/S
Model	522A	55	Rota Screen
Type	Vibrating	Disc	Rotary
Dimensions			
Length (m)	5.4	4.8	12.2
Width (m)	2.2	1.7	3.2
Height (m)	1.4	1.1	NA
Weight (kg)	3,032	NA	NA
Incline (degrees)	4	0	0-7
Motion	Gyrating	NA	Rotating
Motor			
HP	7.5	2/7.5	125
RPM	1,200	NA	NA
Screen Openings	6.35 mm and 1.0 mm	-2.5 cm	114 mm
Screen Size			
Length (m)	3.7	NA	NA
Width (m)	1.5	NA	NA
Thickness (mm)	NA	NA	19
Motion RPM	211	NA	NA
Diameter (cm)	8.9	NA	NA
Norm Capacity (Mg/hr)	5.45	NA	NA
Peak Capacity (Mg/hr)	NA	NA	56.8
Capital Cost ($)	NA	NA	160,000

Source: Equipment manufacturers.

TABLE C-5

EQUIPMENT DATA - DRYER

Manufacturer	Guaranty Performance
Model	1,005-400
Type	Rotary Suspension
Dimensions	
Length	12.2 m
Diameter	3.0 m
Weight	19,318 kg
Voltage	460 v/3/60 Hz
Airflow	10.4 m^3/sec
Velocity	22.9 m/sec
Fire Protect	Waterspray
Dust Control	None
Ancillary Equipment	20 HP Motor, Airlock, Rock Trap, Cyclone
Norm Capacity	6.7 Mg/hr
Peak Capacity	6.8 Mg/hr
Percent Moisture Reduced	3.5
Energy Consumed	1.24×10^6 KJ/Mg
Capital Costs	$176,000

Source: Equipment manufacturer.

TABLE C-6

EQUIPMENT DATA - DENSIFIER

Manufacturer	Heil
Model	HTP-1,000
Type	Compactor
Dimensions	
Length	9.1 m
Width	2.4 m
Height	3 m
Weight	15,909 kg
Voltage	460/230
Cylinder Pressure	141 kg/cm^2
Stroke	38 sec
Volume	2.8 m^2
Norm Capacity	45-55 Mg/hr
Peak Capacity	136 Mg/hr
Capital Cost	$35,000-$40,000

Source: Equipment manufacturer.

TABLE C-7

EQUIPMENT DATA - STORAGE AND RETRIEVAL BINS

Manufacturer	Miller Hoht	American Sheet Metal	Atlas	Sprout Waldron
Model	Type "H"	DRB-6	T3	LC-50
Type	Twin Screw Traversing Unloader	Doffing Roll Bin	Sweet Bucket	Live Center Bin
Dimensions				
Length (m)	18.3	11.4	25.8 (Base Diameter)	7.3
Width (m)	5.8	2	21.9 (Bin Sheet Base Diameter)	3.5
Height (m)	10	5.9	6.1 (Deck Diameter)	9.3
Voltage	460	NA	480	NA
Power (kw)	112	NA	NA	NA
Motor				
HP	150,1/2	NA	40,7.5	24
RPM	NA	NA	NA	NA
Discharge	2 Screws/ Variable Pitch	4 Screws	Sweep Bucket	6 Vertical Screws through center
Mechanism	Traverse drive	8 doffing rolls	4 Conveyors	2 Horizantal screws at bottom
Storage Capacity (m^3)	850 (142 Mg)	34 (5.7 Mg)	2,727 (455 Mg)	125 (21 Mg)
Discharge Rate (Mg/hr)	55	Variable	Variable	Variable
Capital Cost ($)	74,540	NA	687,000	NA

Source: Equipment manufacturers.

TABLE C-8

EQUIPMENT DATA - CONVEYORS

Manufacturer	Semco	PSI	PSI	Maytran	Rexnord	Stephens-Adamson
Model	--	--	--	9375z	Style "A"	HV C 84 x 245 x 13.25 x 20 HP
Type	Pneumatic	Pneumatic	Pneumatic	Z-Pan	Apron	Vibrating
Voltage	4,160	NA	NA	460	NA	NA
Pressure (kg/m^2)	24-34	3,168	2,464	NA	NA	3-60 x 230/460
Airflow (m^3/sec)	5.7	3.8	1.1	NA	NA	NA
Velocity (m/sec)	35.7	NA	36.6	NA	NA	NA
Width (diameter)	4.4 cm	35.6 cm	20.3 cm	2.08 m Flight	2.4 m Flight	NA
Motor HP	600	200	60	7.5,50	NA	NA
Length	NA	NA	NA	22.9 cm Flight	30.5 cm Flight	NA
Depth	NA	NA	NA	15.2 cm Flight	15.2 cm Flight	NA
Incline (degrees)	NA	NA	NA	NA	0-20	NA
Speed (cm/sec)	NA	NA	NA	9.1-15.2	0-20.3	NA
Rollers						
Inboard/Outboard	NA	NA	NA	Inboard	Outboard	NA
Stress (cm-kg)	NA	NA	NA	86,250	104,650	NA
Diameter (cm)	NA	NA	NA	10.16	12.7	NA
Thickness (cm)	NA	NA	NA	3.65	7.14	NA
Table Width (m)	NA	NA	NA	NA	NA	2.1
Thickness (cm)	NA	NA	NA	NA	NA	0.95
Incline (degrees)	NA	NA	NA	NA	NA	5 decline
Stroke (cm)	NA	NA	NA	NA	NA	2.54
Motion	NA	NA	NA	NA	NA	30°-458 cpm
Motor HP	NA	NA	NA	NA	NA	20
RPM	NA	NA	NA	NA	NA	1,200
Idler Pulleys Incline	NA	NA	NA	NA	NA	NA
Spacing	NA	NA	NA	NA	NA	NA
Normal Capacity (Mg/hr)	45	NA	3.6	NA	NA	40.8
Peak Capacity (Mg/hr)	72.7	41	9.1	45.4	NA	54.4
Capital Costs ($)	NA	NA	NA	NA	NA	21,600

Source: Equipment Manufacturers.

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TABLE C-8 (continued)

Manufacturer	Stephens-Adamson	Carrier-Rexnord	Fairfield	Continental	Iron Hustler	Iron Hustler
Model	HVC 90 x 305 x 15.8 x 25 HP	72 inches	60 inches	60 inches	Inclined trough	Piano hinge
Type	Vibrating	Vibrating	Belt	Belt	Belt	Flight
Voltage	3-60 x 230/460	NA	NA	NA	120/460	440
Pressure	NA	NA	NA	NA	NA	NA
Airflow	NA	NA	NA	NA	NA	NA
Velocity (m/sec)	NA	NA	NA	NA	NA	NA
Width (diameter) (m)	NA	NA	1.5	1.5	1.5	2.1
Motor HP	NA	NA	NA	NA	NA	20
Length (m)	NA	NA	NA	NA	NA	5.2
Depth (m)	NA	NA	NA	NA	NA	1.2
Incline (degrees)	NA	NA	22	20	22	34
Speed (cm/sec)	NA	NA	76.2	109	NA	NA
Rollers			NA	NA	NA	NA
Inboard/Outboard	NA	NA	NA	NA	NA	NA
Stress	NA	NA	NA	NA	NA	NA
Diameter (cm)	NA	NA	NA	NA	NA	NA
Thickness (cm)	NA	NA	NA	NA	NA	NA
Table Width (m)	2.3	1.8	NA	NA	NA	NA
Thickness (cm)	0.95	NA	NA	NA	NA	NA
Incline (degrees)	5° decline	1 decline	NA	NA	NA	NA
Stroke (cm)	2.54	NA	NA	NA	NA	NA
Motion	30° 450 CPM	NA	NA	NA	NA	NA
Motor HP	25	15	NA	15	20	NA
RPM	1,200	NA	20°	NA	NA	NA
Idler Pulleys Incline (degrees)	NA	NA	NA	35	35	NA
Spacing (m)	NA	NA	NA	1.5	NA	NA
Normal Capacity (Mg/hr)	40.8	NA	NA	NA	54.5	54.5
Peak Capacity (Mg/hr)	54.4	45	55	NA	90.9	90.9
Capital Costs ($)	25,300	NA	NA	NA	NA	35,000

TABLE C-9

EQUIPMENT DATA - BAGHOUSES

Manufacturer	Griffin	Carter-Day	Griffin	Griffin
Model	JA1200D	144RJ120	JA480S	D-1296
Type	Reverse Jet	Reverse	Reverse	Reverse Jet
Height (m)	4.7	9.8	4.7	8.8
Length (m)	12.8	NA	7.3	12.2
Width (m)	3.3	4.3	1.7	4.7
No. bags	1,200	144	480	1,296
Cloth Area (m^2)	997	355.5	398.8	1,077
No. Modules	10	1	4	1
Airflow (m^3/sec)	30.4	9	12.4	47.2
Cost	NA	NA	NA	$89,000

Source: Equipment manufacturers.

APPENDIX D

EQUIPMENT INSTALLATIONS

TABLE D-1

SHREDDER INSTALLATIONS

Location	Start-up	Shredder Type & Quantity	Type of waste	Manufacturer's Rated capacity (tons per hour)	Use of Products	Status
ALASKA						
Sitka	1976	1 vertical	municipal	15 TPH	landfill	operational
CALIFORNIA						
Los Angeles	1975	1 vertical	municipal	15 TPH	landfill	pilot project
San Diego	1976	1 horizontal	municipal	35 TPH	pyrolysis	pilot project
COLORADO						
Alamosa	1972	1 vertical	municipal	15 TPH	landfill	operational
Pueblo	1975	2 vertical	municipal	20 TPH	landfill (w/ferrous separation)	operational
Salida	1974	1 vertical	municipal	15 TPH	landfill	operational
CONNECTICUT						
Ansonia	1974	1 horizontal	OBW	30 TPH	ferrous recovery & incineration	operational
DELAWARE						
New Castle County	1972	2 horizontal primaries 2 horizontal secondaries	municipal	50 TPH (primaries)	ferrous recovery & landfill	operational
FLORIDA						
Brevard County	1976	2 horizontal	municipal & OBW	75 TPH	ferrous recovery & landfill	operational
Ft. Lauderdale	1973	1 horizontal	municipal & OBW	60 TPH	incineration	operational
Pompano Beach	1972	1 vertical	municipal	15 TPH	landfill	operational
	1978	1 vertical	municipal	60 TPH	landfill & codisposal tests	operational
GEORGIA						
Atlanta	1976	1 horizontal	municipal	60 TPH	bale landfill	operational
Dekalb	1973	2 vertical	municipal	50 TPH	landfill	operational
ILLINOIS						
Chicago	1970	1 horizontal	OBW	25 TPH	landfill	operational
Chicago	1976	2 horizontal primaries 2 vertical secondaries	municipal & OBW municipal	75 TPH each 60 TPH each	energy recovery	start-up
INDIANA						
East Chicago	1977	1 horizontal	OBW	25 TPH	incineration	operational
IOWA						
Ames	1975	2 horizontal 1 horizontal primary 1 horizontal secondary	municipal	50 TPH each	energy recovery	operational

Source: Waste Age, July 1978

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TABLE D-1 (continued)

KANSAS						
McPherson	1975	1 vertical	municipal	15 TPH	landfill	operational
KENTUCKY						
Louisville	1962	1 horizontal	OBW	20 TPH	incineration	operational
LOUISIANA						
New Orleans	1976	1 vertical	municipal	60 TPH	resource recovery & landfill	start-up
		1 horizontal	OBW	60 TPH		
Vermillion Parish	1978	1 horizontal	municipal	40 TPH	landfill	start-up
MAINE						
Lewiston	1977	1 vertical	municipal & OBW	30 TPH	ferrous recovery & landfill	operational
MARYLAND						
Baltimore	1975	2 horizontal	municipal	50 TPH each	pyrolysis	pilot project
Cockeysville	1975	2 horizontal	municipal	70 TPH each	resource recovery & landfill	operational
MASSACHUSETTS						
Holliston	1974	1 horizontal	municipal & OBW	40 TPH	ferrous recovery & landfill	operational
MISSOURI						
St. Louis	1969	1 horizontal	OBW	30 TPH	incineration	operational
MONTANA						
Great Falls	1973	2 vertical	municipal	20 TPH 15 TPH	ferrous recovery & landfill	operational
NEBRASKA						
Omaha	1976	1 horizontal	municipal & OBW	50 TPH	ferrous recovery & bale landfill	operational
NEW JERSEY						
Monmouth	1975	2 vertical	municipal	40 TPH each	ferrous recovery & landfill	operational
NEW YORK						
Elmira	1973	2 horizontal	municipal & OBW	40 TPH each	landfill	operational
NORTH CAROLINA						
Guilford County	1973	1 vertical	municipal & OBW	50 TPH	landfill	operational
OHIO						
Columbus	1975	3 horizontal	municipal & OBW	60 TPH each	ferrous recovery & landfill	operational
Willoughby	1973	2 vertical	municipal	12 TPH each	landfill	operational
OREGON						
La Grande	1978	1 vertical	municipal	20 TPH	ferrous recovery & landfill	operational
Lane County	1977	2 horizontal 1 horizontal primary 1 horizontal secondary	municipal	65 TPH (primary) 45 TPH (secondary)	landfill	operational

TABLE D-1 (concluded)

PENNSYLVANIA						
Harrisburg	1970	1 horizontal	OBW	25 TPH	incineration	operational
Charleston	1974	3 vertical	municipal & OBW	75 TPH	ferrous recovery & landfill	operational
Georgetown County	1974	1 vertical	municipal	20 TPH	ferrous recovery & landfill	operational
Beaufort	1975	1 vertical	municipal	20 TPH	ferrous recovery & landfill	operational
Williamsburg County	1973	1 vertical	municipal	20 TPH	landfill	operational
SOUTH DAKOTA						
Aberdeen	1975	1 vertical	municipal	20 TPH	seperation & landfill	operational
TEXAS						
Houston	1965	1 horizontal	municipal	40 TPH	resource recovery	operational
Odessa	1974	1 horizontal	municipal	50 TPH	ferrous recovery & soil enrichment	operational
Texarkana	1977	1 horizontal	industrial	20 TPH	ferrous recovery & landfill	operational
VIRGINIA						
Norfolk	1975	1 horizontal	municipal & OBW	30 TPH	incineration	operational
WASHINGTON						
Cowlitz County	1976	1 horizontal	municipal	50 TPH	landfill	operational
Seattle	1978	1 vertical	industrial	20 TPH	landfill	operational
Tacoma	1971	1 horizontal	OBW	40 TPH	landfill	operational
WISCONSIN						
Appleton	1974	2 horizontal	municipal	15 TPH each	ferrous recovery & landfill	operational
Madison	1967	1 horizontal 1 vertical	municipal	10 TPH 15 TPH	landfill w/ferrous separation	operational
Milwaukee	1976	2 horizontal 2 vertical	municipal pre-shredded municipal	75 TPH each 60 TPH each	energy recovery & ferrous separation	operational
CANADA						
Edmonton, Alberta	1970	2 vertical	municipal	25 TPH each	landfill	operational
Hamilton, Ontario	1972	3 vertical	municipal	45 TPH each	ferrous recovery & incineration	operational
St. Catharines, Ontario	1970	2 vertical	municipal	30 TPH each	landfill	operational
Toronto, Ontario	1975	1 horizontal	municipal	20 TPH	ferrous recovery & landfill	operational
Regina, Saskatchewan	1973	1 horizontal	municipal	25 TPH	landfill	operational

TABLE D-2

SOLID WASTE MAGNET INSTALLATIONS

Belt Magnets

Resource Recovery Facility
Division of Browning-Ferrous
9225 Lawndale
Houston, TX

Resource Recovery Corporation
Division of Browning-Ferrous
Holliston, MA

c/o M&T Prod. of Canada Ltd.
c/o E. Ham. Solid Waste
Reduction Unit
Kenoca Avenue, Hamilton
Ontario, Canada

Lambson's-Lane
Wilmington, DE

Solid Waste Reduction Plant
15th Street and River Road
Great Falls, MT

M&T Chemicals, Inc.
7000 Kapkowski Road
Elizabeth, NJ 07201

City of Ames
Ames, Iowa

City of Toronto

Company of Onedaga
Shredder Plant
Town of Salina, NY

Zupan Enterprises
Pueblo, Colorado

Aerobic Destructor
Fayetteville, AK

Aberdeen. SD

City of St. Catherines
Ontario, Canada

Envirogetics, Inc.
1600 16th Street
Hoboken, NJ

Heil - Venezuela
South America

Texas Sanitary Landfill
117 Church Lane
Cockeysville, MD 21030

Ministry of the Environment
Experimental
North York, Toronto
Canada

Pleasant Grove, UT

Lehigh County Authority
Allentown, PA

Milwaukee, WI
(2 units)

Canterbury City Council
Canterbury, Australia

M&T Products of Canada
Hamilton, Ontario
Canada

Municipal Services
Old Northport Road
Smithtown, NY

Sources: Equipment Manufactures.

TABLE D-2 (concluded)

Drum Magnets
Cowlitz County, Washington

City of Harrisburg, Pennsylvania

City of Baltimore, Maryland

Refuse Energy System Company
Saugus, Massachusetts

Gulf Contracting Company
Brevard County, Florida

Cass County Reclamation
Peculiar, Missouri

Beaumont Birch Company
Baltimore, Maryland

Union Carbide Corporation
Linde Division
South Charleston, West Virginia

Special Magnets
City of Appleton, Wisconsin

Jersey City, New Jersey

Reynolds Aluminum Company

City of Franklin, Ohio

U.S. Bureau of Mines Raw Refuse Plant
Edmonston, Maryland

Garrett Research
Levern, California

National Center for Resource Recovery
City of Washington, D.C.